INSTITUTE FOR DEFENSE ANALYSES

What to Buy? The Role of Director of Defense Research and Engineering (DDR&E)

Lessons from the 1970s

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14. ABSTRACT
Defense acquisition programs, which had their initial inception in the 1970s, performed exceptionally well by many measures. The management of acquisitions during this period is examined in detail by means of case studies, and contrasted with earlier and later periods, to identify key factors and formulate promising policy initiatives. Previous findings about the crucial importance of decisions in the very earliest conceptual phase are strongly confirmed and success is shown to have very often hinged on effective intervention by the Director of Defense Research and Engineering (DDR&E) even before the equivalent of todays Matériel Development Decision. Factors in DDR&Es successes included a focus on the intersection of technology and military need, DDR&Es background of institutional success and the prestige and credibility it established, a compact and highly capable staff, a strong culture of objectivity and absence of either pessimistic or optimistic bias, excellent internal and external communications, a very sharp focus on things that made a real difference, and close meshing with the top management of the Department of Defense and its priorities. Finally, ways that these lessons could be effectively applied in todays environment are explored.

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Executive Summary

Research has consistently shown that the outcomes of development and acquisition programs, both civil and military, are largely determined by the soundness of the very early decisions on the concept to be pursued. Programs that are started with inadequate or unrealistic planning frequently go awry in ways that can only be partly put to rights later, if at all. This study focuses on the responsibility, authority, and ability of the Office of the Secretary of Defense to assist him in such early decisions by providing independent advice and assessments of the appropriate way to meet real needs with sound technical and operational concepts and affordable resource demands. This Institute for Defense Analyses (IDA) research documents how key elements of this process were conducted during the 1970s when the then-newly established Office of the Director of Defense Research and Engineering (DDR&E), assisted by a relatively small staff, served as the principal independent advisor to the Secretary on what new weapon systems should be acquired. This empowerment of what was, in effect, the first Defense Acquisition Executive, grew out of the post-World War II struggles to establish unity of effort across the Defense Department and built on the prestigious reputation of the civilian scientists and engineers that had provided exemplary technical leadership during that war.

Since the 1970s, the acquisition decision function then provided by DDR&E has undergone numerous changes; first with the office being retitled as the Under Secretary for Research and Engineering (USD R&E) and substantially expanded, and then, ten years later, with the formal establishment of the Defense Acquisition Executive (USD(Acquisition)) and the reestablishment of the DDR&E as his subordinate. At present the authority to decide on starting new acquisition programs lies with the Under Secretary of Defense for Acquisition, Technology & Logistics (USD (AT&L)) as Chairman of the Defense Acquisition Board. He is assisted in this responsibility primarily by the Director of Portfolio Systems Acquisition, and the DDR&E, recently renamed the Assistant Secretary (Research and Engineering) (ASD(R&E)). Within this structure the Director of Systems Engineering, reporting to the ASD(R&E), has been specifically empowered by the Weapon Systems Acquisition Reform Act of 2009 (WSARA 2009) to play a strong role in the developmental planning function, which is a proper venue for early assessments and decisions on new acquisition programs.

The current arrangements are too new to have established a record of effectiveness and this study intends no judgments on the organizational structure now in place. We have focused on extracting lessons from the 1970s when the DDR&E performed essentially all of the functions now assigned to the foregoing officials and have couched our resulting recommendations in the same DDR&E vernacular, without attempting to map them in detail into the current organizational structure. At the request of the staff of DDR&E, IDA looked back through the history of the office to draw lessons that might help strengthen the quality and effectiveness of its intervention in early Major Defense Acquisition Program (MDAP) decision-making.

World War II: The Office of Scientific Research and Development (OSRD)

In 1940, fearful that World War II would soon engulf the United States and anxious to combat the Nazi menace, President Franklin D. Roosevelt chartered the Office of Scientific Research and Development (OSRD). Reporting to the White House, it was authorized and funded to mobilize the science and technology community for wartime research and development (R&D). Although the U.S. Military Services, hereafter referred to as the Services, were not required to turn to OSRD for R&D, they very often did. At a cost of only about $500 million, the OSRD developed a remarkable array of weapons and weapons systems. When no technological solution was possible, one or another of the OSRD organizations specializing in the new science of operations research, could often help devise better tactical or operational solutions. Or those involved in direct support might find ways to improve the performance of existing equipment.

Rather than merely accept military direction, OSRD scientists and engineers met with knowledgeable Service personnel to discuss operations and problems, propose technical solutions, and, when it was agreed that they had it right, begin development. As development proceeded, OSRD engineers and scientists continued to work closely with users, involving them ever more deeply in engineering and operational testing – often in the field in combat against the enemy – until the system was ready to be handed over for production and operational service. Not only did development generally proceed very quickly using this process, but the quality of what was developed was so high that, in many cases, it proved difficult to develop anything significantly better for some years after the war. At the end of the war OSRD was quickly closed down, but its heroic image lingered as one of the few in the multitude of wartime agencies remembered with respect.

DDR&E: Establishment and First Decade

After 1945 there was an extended period of debate and adjustment as new structures for defense were worked out. The dramatic news of the Soviet Union's *Sputnik* satellite launching in October 1957 created a sense of threat and urgency that President Dwight D. Eisenhower used to demand long-desired changes. Among them was a strongly centralized overall direction for defense R&D, which would operate under a top civilian official with wide powers, called the Director of Defense Research and Engineering. In response, Congress passed a sweeping reorganization act in August 1958 that gave the President much of what he asked for, including a powerful DDR&E.

The DDR&E in the 1970s

The year 1969 brought a new President and a new Deputy Secretary of Defense, David Packard, who developed and implemented a wide range of policies intended to improve acquisition. While the resulting "Packard policies" sought to get OSD out of the details of program management, they emphasized and strengthened the DDR&E's role as an arbiter of what was and was not to be acquired, and as a champion of technological innovation. By this point, the Office of the DDR&E was a small (fewer than 150) but very select and elite staff of well-qualified engineers and applied scientists from industry or government technical organizations, with a high proportion beyond the GS-15 level on the government pay scale.

The DDR&Es of the 1970s implemented mission analysis and systems engineering at the mission area level to explore the potential of technology to transform the structure of warfare, rather than simply improve the performance of individual systems. Mission area systems engineering was at the root of the ODDR&E's greatest successes in the 1970s. In a minority but still significant number of cases it led to innovations with broad impacts. It was also a focus of criticism by those who wished to limit OSD to routine management and coordination functions and reassert the power of the Services.

In the 1980s, the DOD explicitly shifted the focus of innovation to the military departments, reducing the power of the new USD R&E[1] to affect major acquisition choices and bringing a definite end to the pattern set by prior DDR&Es.

Accomplishments and Lessons

The 1970s are remembered as an era when DOD produced especially innovative and successful programs. There is no conclusive way to measure this, let alone distinguish among its causes. But many of the long list of notably successful programs and systems from the period are still in front-line service. Even when there were serious development problems, they usually were dealt with effectively, often with the DDR&E taking a hand to restructure a faltering effort. For example, one factor that is almost always associated with serious problems is cost growth. Yet statistical analysis shows that programs that had their inception in the late 1970s, after the ODDR&E approach had fully matured had, in general, better cost growth records than those of any other period between 1970 and 2000.

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[1] In 1977, the new USD (R&E) position subsumed the responsibilities of the DDR&E and the title was abolished until reestablished under the USD (Acquisition & Technology) in 1986.

Principal factors contributing to the ODDR&E's success included:

- Operating at the intersection between technology and military need; working in close cooperation with other relevant OSD offices; and focusing particularly on the critical period at the inception of a concept, where the success or failure of programs is principally determined.
- Use of the ODDR&E's history and heritage to establish and uphold the validity of its model of civilian scientists and engineers exercising a dominant voice in deciding what programs to pursue and how to structure them.
- A compact and elite staff that had the qualifications and qualities to powerfully and creatively support the top executives of the ODDR&E in meeting their objectives.
- A strong culture of objectivity and an absence of either pessimistic or optimistic bias, backed by the systematic use of comparative analysis.
- Excellent communications within the ODDR&E and with the other organizations that played key roles in the "what to buy" decision.
- A very sharp focus on the things that made a real difference.
- Close meshing with the top management of DOD and its priorities.

Recommendations

A principal goal of this research was to identify attributes of the successful ODDR&E of the 1970s that could be effectively applied within the current structure and procedures of the Department to improve the process for starting and developing new weapon system acquisition programs. Under the current structure, the USD (AT&L) has both statutory and delegated responsibility and authority over all aspects of defense acquisition. He has delegated specific responsibilities for strengthening the early development planning phases of the acquisition process to the Systems and Engineering Directorate in the office of the DDR&E and this paper's recommendations are consonant with that framework.

The three key recommendations are:

1. Ensure that personnel experienced in system design and operations analysis, and free of bias and conflicts of interest, are directly and substantively involved in and approve the early concept formulation and requirements determinations for all new major weapon systems, prior to formal Defense Acquisition Executive approval of a new program start at the Matériel Development Decision point.
2. Increase the authority of the AT&L staff to initiate and guide promising new and innovative technological approaches, including Advanced Capability

Technology Demonstrations that can lead to important new military capabilities as well as attract highly qualified scientists and engineers to government service.

3. Empower the DDR&E to review and approve the adequacy of every development plan and associated funding profile as a condition for starting all new major acquisition programs.

Other supporting recommendations to these three key recommendations include positioning the ODDR&E at the technology-operations interface; making use of its heritage to reinforce its authority; continuously improving staff quality through training and emphasis on personal skills development; promoting objectivity and close communication among the staff; and institutionalizing learning from experience.

Contents

Appendices

1. Background, Methodology, and Approach

Research has consistently shown that the outcomes of development and acquisition programs, both civil and military, are largely determined by the soundness of the very early decisions on the concept to be pursued. Programs that are started with inadequate or unrealistic planning frequently go awry in ways that can only be partly put to rights later, if at all. This study focuses on the responsibility, authority, and ability of the Office of the Secretary of Defense to assist him in such early decisions by providing independent advice and assessments of the appropriate way to meet real needs with sound technical and operational concepts and affordable resource demands. This Institute for Defense Analyses (IDA) research documents how key elements of this process were conducted during the 1970s when the then-newly established Office of the Director of Defense Research and Engineering (DDR&E), assisted by a relatively small staff, served as the principal independent advisor to the Secretary on what new weapon systems should be acquired. This empowerment of what was, in effect, the first Defense Acquisition Executive, grew out of the post-World War II struggles to establish unity of effort across the Defense Department and built on the prestigious reputation of the civilian scientists and engineers that had provided exemplary technical leadership during that war.

Since the 1970s, the acquisition decision function then provided by DDR&E has undergone numerous changes; first with the office being retitled as the Under Secretary for Research and Engineering (USD R&E) and substantially expanded, and then, ten years later, with the formal establishment of the Defense Acquisition Executive (USD(Acquisition)) and the reestablishment of the DDR&E as his subordinate. At present the authority to decide on starting new acquisition programs lies with the Under Secretary of Defense for Acquisition, Technology & Logistics (USD (AT&L)) as Chairman of the Defense Acquisition Board. He is assisted in this responsibility primarily by the Director of Portfolio Systems Acquisition, and the DDR&E, recently renamed the Assistant Secretary (Research and Engineering) (ASD(R&E)). Within this structure the Director of Systems Engineering, reporting to the ASD(R&E), has been specifically empowered by Weapon Systems Acquisition Reform Act of 2009 (WSARA 2009)[1] to

[1] Public Law 111-23, 22 May 2009, 123 Stat. 1704.

play a strong role in the developmental planning function, which is a proper venue for early assessments and decisions on new acquisition programs.

The current arrangements are too new to have established a record of effectiveness and this study intends no judgments on the organizational structure now in place. We have focused on extracting lessons from the 1970s when the DDR&E performed essentially all of the functions now assigned to the foregoing officials and have couched our resulting recommendations in the same DDR&E vernacular, without attempting to map them in detail into the current organizational structure. At the request of the staff of DDR&E, IDA has prepared this study considering how DDR&E may strengthen the quality and effectiveness of its intervention in Major Defense Acquisition Program (MDAP)[2] decision-making, specifically in light of the experiences of the DDR&E of the 1970s, and its immediate successor, the Under Secretary of Defense for Research and Engineering (USDRE), in the early 1980s – the last period in which DDR&E had been deeply involved in the "what to buy" decision.[3] Thus, this is, in effect, a "lessons learned" study, looking back after a lapse of more than three decades.

The methodology and approach of this study have been shaped both by its circumstances and objective. The objective is to provide DDR&E and his or her managers and staff today and in the future with options for possible improvement in the management of research and engineering programs within their designated sphere of responsibility. It is oriented toward practitioners rather than theorists and intended to add to the body of practice rather than to the body of abstract knowledge, broadly conceived.

A key fact of the study is that it is being conducted more than three decades after the events it is examining. Extensive research has demonstrated the unreliability of unaided human memory as a guide to specific events and sequences.[4] These problems grow worse over time, and after thirty to forty years they are acute. Moreover, many participants are dead or debilitated by age.

The prospects were scarcely brighter with respect to documentary evidence. The principal members of the study team had direct experience with the DDR&E of the 1970s and recognized that the office did not conduct its affairs in a structured or regular form that left a dense documentary record.[5] The primary investigator had retained in his files a

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[2] As defined in 10 U.S.C. §2430.

[3] Reflecting usage then and now, we will use the designations such as DDR&E and USDRE to denote both the official holding the office and the collective organization he or she headed. Qualifications will be added where necessary for clarity.

[4] Daniel L. Schacter, *Searching for Memory: The Brain, the Mind, and the Past* (New York: Basic Books, 1996).

[5] William D. O'Neil joined DDR&E as a technical Staff Specialist in the Office of Ocean Control (under the Deputy Director for Tactical Warfare Programs) in June 1973, becoming the director of the office in 1977, where he continued to serve (with some expansion of responsibilities and under various titles)

considerable quantity of unclassified internal documents from that period which have been valuable research materials for this study.[6] But beyond these the available records are spotty and unsystematic, and the resources of the study could not support intensive archival search for further material. Published accounts of the development of major systems often omit or minimize the role of DDR&E, even when there is evidence that it was very significant.

In light of these considerations, this paper has been cast as an extended series of management case studies. These studies have been embedded within an overall narrative framework to lend coherence and perspective, generally in accordance with the principles published in a widely-cited paper by Oxford University management scientist Bent Flyvberg. His paper serves as a guide to providing the most effective and reliable results in situations of this sort.[7]

The selection of case material has been governed, in part, by the availability of written evidence. Some important aspects of DDR&E's work are little documented. For instance, both of the authors were involved in development of antisubmarine warfare (ASW) tactical and surveillance sensors and they are in contact with others who played significant roles. But because virtually all of that work was classified, it is difficult to find useful records and limits the ability of the authors to include case material.

In some cases, particular programs that command special interest have been the subject of academic studies, often doctoral dissertations. Some of these have been based on documents not easily available today and interviews with participants (including DDR&E personnel). Other valuable sources have included near-contemporaneous oral history interviews with the early DDR&Es themselves, in addition to various contemporaneous documents available from other sources – all woven together with the recollections of participants.

Important and relevant source documents, together with copies of contemporary directives and other references that might otherwise not be available, have been digitized and included (in electronic form only) in Appendix D of this paper. The CD containing

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until leaving the government to return to industry in June 1984. From June 1969 to 1973 he had served as a technology advisor in the Office of Program Appraisal on the staff of the Secretary of the Navy, where he had close contact with DDR&E. Gene H. Porter joined the Office of the Assistant Secretary of Defense (Systems Analysis) in 1971 and subsequently held positions of increasing responsibility in that office until retiring in 1980 as the Principal Deputy Assistant Secretary. He subsequently worked in defense industry for ten years before returning to a senior acquisition policy position in OSD in 1990.

6 Because many of these documents are not known to be available elsewhere they have been compiled as an appendix to this study (Appendix D), which is contained on the CD with this study as well as retained in the IDA archives for reference.

7 Bent Flyvbjerg, "Five Misunderstandings About Case-Study Research," *Qualitative Inquiry* 12, no. 2 (Apr 2006): 219-245.

Appendix D is attached to the back cover of this paper. The electronic files on the CD are organized into three folders, Surface Effect Ship Program, Directives and General Management and Policy, Forward Area Air Defense and OTHR. Within each folder, the electronic documents are labeled with a date (year first) and a short, descriptive title, References to these documents are marked (see Appendix D) in the footnotes.

2. Origins and Establishment of the Office of the Director of Defense Research and Engineering (DDR&E)

From a purely managerial perspective, it is possible to simply take the concepts underlying the DDR&E structure as given. To do so, however, could distort our understanding of how the DDR&E of the 1970s functioned, and how that differs from the way it functions today. Thus, we, the IDA study team, will sketch the conceptual background of the DDR&E structure as a starting point.

A. The Development of "Development" and Military Management

Technology has always been important in warfare. In Medieval Europe, the term "engineer" specifically meant "A constructor of military engines," or "One who designs and constructs military works for attack or defense." It was only later that the definition was expanded to include those who fashioned machines or structures for non-warlike use.[8] As modern science developed in the 16th and 17th centuries, scientific knowledge and techniques progressively became incorporated into engineering practice, opening many new technological opportunities. By the 19th century, the pace of technological innovation had increased notably, bringing a number of developments that were of military importance, including affordable iron and then steel in quantity, percussion firearms, steam propulsion for railroads and ships, the revolver, the electric telegraph, repeating firearms, high explosives, smokeless powder, the telephone, automatic weapons, the automobile, wireless telegraphy, and finally aircraft. Yet it was only toward the end of the 19th century that truly industrial production became an important source of military goods. Throughout this period development continued on essentially an individual scale, each innovation the product of one or two engineers aided, perhaps, by a few assistants, operating on very limited capital.

The process for determining which technologies might have military utility was haphazard. Inventors and innovators sometimes managed to persuade the Army or Navy to try their technology. Sometimes political intervention was involved. Or technologically aware officers might champion or even invent new systems. In any event, the process

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8 *Oxford English Dictionary*, 2nd Edition, 1989, s.v. "engineer."

rarely operated smoothly or efficiently. Civilian inventors often had too little understanding of military operations and needs to be able to put forward meaningful and feasible concepts, while even technologically oriented military officers were prone to misconceive what technology could best do for them and how. There were many failed innovations and missed opportunities.

For the most part new systems were procured in one of two ways. Either examples were bought from companies that held rights to the technology, or had special expertise in its application. Or the Army or Navy acquired rights and built systems in their own arsenals, shipyards, or factories. In some instances, for example in shipbuilding, processes emerged for development of new models, but each system was regarded sui generis and there was little conceptualization of a generalized development process applying to systems as a class.

The emergence of the airplane as a major weapon in the wake of World War I began a major transformation in the conceptualization of development and procurement. Because development had not been recognized as a process, there were no provisions in the law to support it. This wreaked havoc with acquisition of aircraft where there was strong demand and opportunity for progress that could only be met through extensive development. After a series of Congressional hearings, a new legal framework was adopted in the Air Corps Act of 1926.[9] This permitted and stimulated major changes in the management of aeronautical acquisition in the U.S. Military Services, hereafter referred to as the Services, and indirectly resulted in the emergence of a more modern concept of acquisition as a process.[10]

As part of their accommodation to the increasing importance of technology, the Services emulated industry in establishing laboratories – first the Naval Research Laboratory (NRL) in 1923, with a broad charter but focused initially on radio and sonar, and then a sprinkling of others in both the Army and the Navy. All of the facilities mixed military personnel with civil service scientists and engineers, in varying proportions, on their staffs. The Great Depression of the 1930s was helpful in making positions at the military labs attractive to qualified civilians. But both the Navy and the Army responded coolly to offers from the civilian academic science community to aid in defense-oriented research.[11] They believed that research for defense purposes was a military function that should remain firmly under military guidance and control.

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9 44 Stat. 780, 2 Jul 1926.

10 I[rving] B[rinton] Holley, Jr., *Buying Aircraft: Matériel Procurement for the Army Air Forces*, United States Army in World War II: Special Studies (Washington, DC: Department of the Army, 1964), Chapters IV. and V.

11 Daniel J. Kevles, “Scientists, the Military, and the Control of Postwar Defense Research: The Case of the Research Board for National Security, 1944-46,” *Technology and Culture* 16, no. 1 (Jan 1975): 20-

The 1920s and 1930s also saw the emergence or rise to prominence of several new technologies that demanded extended and well-supported development processes to realize their military potential, including radio, sonar, tracked armored vehicles, electromechanical computers for weapons control, heavy automatic weapons, and radar. In general, each of these fell under a different department or bureau within the Services, resulting in a diversity of approaches, some more successful than others. For the most part, the Navy acquired broader experience in managing development in non-aeronautical technology areas than the Army. In both services, much of the non-aeronautical development was centered within in-house government operated laboratories or industrial facilities.

1. The Development of Radar in Britain and the United States

Radar was developed as a practical military technology on the eve of World War II. It was important in the conflict, but the manner of its development also played a role of its own.

Rather remarkably, radar was conceived and developed at approximately the same time in more than a dozen nations. Each proceeded in secrecy and largely imagined that it was alone in developing the new technology. How they went about it and what results they got tell much about the development process in these nations.[12] The contrast between radar development in the United States and Britain in particular – and more especially their understanding of the difference – came to influence the views and approach of American scientists and engineers.

As is well known, Great Britain was the first nation to develop radar as a weapons system and put it into wartime service. But radar development actually started in the United States, at the NRL, five years before the British effort began.

During World War I and the period leading up to it there had been several, largely ineffectual, efforts to mobilize American civilian science and technology (S&T) resources under military auspices for the war effort. One of them was the Naval Consulting Board (NCB), chaired by Thomas A. Edison, which included twenty-four members nominated by eleven major engineering and applied science societies. This was the great age of industrial research laboratories in the United States and the NCB proposed that the Navy equip itself with a laboratory of its own, to be operated under

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47, 21. There was no separate Air Force until 1947 and the Marine Corps was not recognized as an independent service until 1977.

12 For comprehensive comparisons see Louis Brown, *A Radar History of World War II: Technical and Military Imperatives* (Bristol: Institute of Physics Publishing, 1999); S[ean] S. Swords, *Technical History of the Beginnings of RADAR* (London: Peter Peregrinus, 1986); or Raymond C. Watson, Jr., *Radar Origins Worldwide: History of its Evolution in 13 Nations Through World War II* (Trafford, 2009).

civilian leadership and reporting to the Secretary of the Navy (SECNAV). Although Edison persuaded Congress to appropriate substantial funds, no action was taken due to opposition from the uniformed Navy. After the war, however, the project was taken up by interested naval officers and in July 1923 the NRL opened on the banks of the Potomac River in Anacostia (where it remains today) with a staff of twenty-four research personnel. It was to operate under the nominal control of the SECNAV and civilian day-to-day direction, but with military control of its program.[13]

The initial staff had all been transferred from Navy groups working on radio or sonar, and both subjects continued to play a predominant role in NRL's program throughout the interwar years. In 1922, even before the lab itself opened, two of its soon-to-be top researchers discovered that the presence of a ship affected radio waves in a way that might be useful for detection and tracking. They proposed a modest program of research to pursue the implications but the naval officers who set the lab's overall agenda were uninterested. Finally, in June 1930 an NRL researcher discovered that aircraft returned radio echoes that were strong enough to be detectable. This time approval was awarded for what eventually became a program to develop radar, the first of its kind.

With extremely limited and initially intermittent funding, NRL researchers developed all of the essential technology for radar and produced experimental sets that were successful in tests at sea and became the prototypes for many of the radars that served the Navy in World War II. Their work also aided the Army Signal Corps Laboratory when it subsequently began exploratory development of radar. But for both the Army and the Navy radar remained a comparatively low priority almost until the war broke out. Despite the stimulus of the war in Europe and the clear prospect of war with Japan, the U.S. Military Services were just beginning to deploy radar widely at the time of the attack on Pearl Harbor in December 1941. Moreover, operational commanders showed relatively little understanding or interest, with the result that there had been little urgency in putting a radar warning service in operation to protect Pearl Harbor, thus allowing the Japanese attackers to achieve complete surprise.[14]

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[13] David Kite Allison, *New Eye for the Navy: The Origin of Radar at the Naval Research Laboratory*, NRL Report 8466 (Washington, DC: Naval Research Laboratory, 29 Sep 1971), 5-38, 46-53.

[14] For Navy development see Allison, *New Eye for the Navy* and L[awrence]. A. Hyland, "A Personal Reminiscence: the Beginnings of Radar, 1930-1934," and Robert M[orris] Page, "Early History of Radar in the US Navy," in *Radar Development to 1945*, ed. Russell W. Burns (London: Peter Peregrinus & Institution of Electrical Engineers, 1988), as well as the broader works cited previously. For the Army see Dulany Terrett, *The Signal Corps: The Emergency (To December 1941)*, United States Army in World War II: The Technical Services (Washington, DC: Office of the Chief of Military History, Department of the Army, 1956), *passim*. For brief summaries of the failings of the Hawaiian commands regarding air defense see Stephen L. Johnson, "The Aircraft Warning Service, Hawaii and The Signal Company, Aircraft Warning, Hawaii," *IEEE Aerospace and Electronic Systems Magazine* 6, No. 12 (Dec 1991): 3-7 and John W. Lambert and Norman Polmar, *Defenseless: Command Failure at Pearl Harbor* (St. Paul, MN: MBI, 2003), 43-51.

In Britain, the story of radar development could scarcely have been more different. In 2000 days it went from the initial discoveries to a system that functioned well enough to provide a great boost to air defense capabilities. Senior American S&T leaders began learning of the British development soon after the European war opened in the fall of 1939 – before many were aware of developments in their own country. The picture they received was one of a very challenging and complex development conceived and carried out with tremendous efficiency and dispatch under the direction of distinguished civilian scientists from academe – men much like themselves. As they learned more of the slow and halting developments by the U.S. Military Services, the contrast seemed stark.[15]

The reality of the British achievement was unquestionably impressive, but its lessons were less clear-cut. There was far deeper involvement of government scientists and engineers than U.S. researchers realized, the senior scientists had, for the most part, gained a great deal of operational air defense experience in World War I, and the development did not go nearly as smoothly as it seemed from afar. Technically aware senior officers of the Royal Air Force played key roles, and it seems likely that important aspects of the program would have benefitted materially from earlier and deeper Service involvement.[16] But it is the American perception that matters for this analysis. In many respects, it was the foundation myth of the civilian organization that dominated advanced technology development in the United States between 1940 and 1945. In this it served its purpose, for in many ways the American effort came closer to their vision than its supposed British prototype had.

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[15] The picture as they understood it at that time is represented in Henry E. Guerlac, *RADAR in World War II*, vol. 8, The History of Modern Physics, 1800-1950 (Los Angeles/New York: Tomash Publishers/American Institute of Physics, 1987), 122-74, 224-31. Although not published until 1987 this text had been completed immediately following the war, as OSRD closed down.

[16] Phillip Edward Judkins, *Making Vision Into Power: Britain’s Acquisition of the World's First Radar-Based Integrated Air Defence System, 1935-1941* (Ph.D. diss, Cranfield University Defence College of Management and Technology, 2007).

Figure 1. British CH Radar Station, in the Late 1930s, with Transmitter Towers on the Left and Receiver Towers to the Right

In Europe, World War II broke out in September 1939, more than two years before Pearl Harbor. European nations had been rearming since the mid-1930s, bringing an increased focus on technology development. Even before the United States entered the war in December 1941, many came to believe that America had fallen badly behind in developing new technologies for warfare. The Services, at least partly, joined in this perception, blaming inadequate funding, but others saw a failure of leadership and vision.[17]

2. The National Defense Research Council (NDRC) and the Office of Scientific Research and Development (OSRD)

During both the Civil War and World War I, efforts had been made to mobilize American science for war, leading respectively to the formation of the National Academy of Sciences and its National Research Council.[18] The most prominent leaders of American academic science and engineering well remembered what they felt had been the largely ineffective use of their potential in World War I, and, spurred by their vision

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17 Generally, funding for the military services in the United States had kept pace with that of major foreign states through the 1920s and into the 1930s – an unprecedented situation for the United States in peacetime. It was only with the increases in armaments spending in Europe and Japan in the later 1930s that the United States fell relatively behind. See William D. O'Neil, *Interwar U.S. and Japanese National Product and Defense Expenditure*, CIM D0007249.A1 (Alexandria, VA: Center for Naval Analyses, Jun 2003).

18 "History of the National Academies," http://www.nationalacademies.org/about/history.html; Guy Hartcup, *War of Invention: Scientific Developments, 1914-18* (London: Brassey's Defence Publishers, 1988), 2, 31-3, 42-3; Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970* (New York: Penguin Books, 1990), 118-26.

of British success in radar development, wanted something quite different this time [19] Under the forceful leadership of Vannevar Bush, they seized the initiative, persuading President Franklin Roosevelt to use his powers to order the establishment of a National Defense Research Council (NDRC), directed by Bush, in mid-1940, when the fall of France to the Nazi blitzkrieg alarmed Americans and prompted a variety of measures to strengthen national defense. A 1941 reorganization created a higher-level OSRD, with the NDRC as one of several research organizations under it.[20]

Figure 2. Vannevar Bush, Head of the OSRD

The U.S. Military Services were not required to go to OSRD for new systems – they retained the authority to develop them internally and/or go out to industry. But at least to many military leaders it quickly became apparent that the OSRD offered capabilities that were not matched anywhere else.

Over the course of the war the OSRD spent about half a billion dollars on research and development (R&D) contracts with a wide variety of universities and industrial firms.[21] This amount, equivalent to roughly five billion dollars in today's terms, covered all the work on the atomic bomb through the end of 1942, and the development of all U.S. microwave radars, the proximity fuse, a wide variety of rocket weapons, specialized

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[19] Daniel J. Kevles, "Scientists, the Military, and the Control of Postwar Defense Research: The Case of the Research Board for National Security, 1944-46," *Technology and Culture* 16, no. 1 (Jan 1975): 20-47, 21-3.

[20] Irvin Stewart, *Organizing Scientific Research for War: The Administrative History of the Office of Scientific Research and Development*, *Science in World War II* (Boston: Little, Brown & Co., 1948).

[21] The appendix to Larry Owens', "The Counterproductive Management of Science in the Second World War: Vannevar Bush and the Office of Scientific Research and Development," *Business History Review* 68 (Winter 1994): 515-76, lists the contracts and amounts.

vehicles for waterborne invasions, pioneering guided weapons, advanced torpedoes, electronic countermeasures, new explosives, antimalarials, DDT, penicillin production methods, and a host of other equipment and systems, as well as operations research and other support for military operations and many important advances in basic knowledge for weapons development. It was almost universally regarded as a tremendous accomplishment at a very reasonable price.[22]

OSRD's relations with the U.S. Military Services mixed competition, cooperation, and mutual co-optation.[23] Bush, OSRD's leader, proved highly adept at managing interpersonal relations and dealing with official Washington, and the top military leadership quickly recognized that they would do much better by making use of his willingness to help than by fighting him. One of the reasons for his success was that he strongly disavowed any ambitions to build a permanent bureaucratic structure. Unlike most of the wide assortment of other wartime agencies, OSRD left a heroic legacy, boosted by the very able and articulate public information efforts of its personnel and supporters during and after the war.[24]

3. The Lasting Influence of OSRD

Although it left no permanent bureaucratic edifice, the OSRD did have several enduring legacies. For the purposes of this study, the most important was establishing a precedent for strong overall direction of military-oriented R&D.[25] To understand this legacy, which is a major part of this study, we need to look more deeply into how it was created and what gave it power.

It benefitted greatly from the quality of its leadership, particularly that of Vannevar Bush. By 1940 he had left his post as vice president of the Massachusetts Institute of Technology (MIT) and was serving in Washington as president of the Carnegie

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22 James Phinney Baxter, 3rd, *Scientists Against Time* (Cambridge, MA: MIT Press, 1946) and "Office of Scientific Research and Development," http://history.sandiego.edu/gen/WW2timeline/OSRD.html.

23 Stewart, *Organizing Scientific Research for War*, Chapter X, describes this in discreet terms. For a view from the other side of the divide see Harold G[ardiner] Bowen, *Ships, Machinery, and Mossbacks; the Autobiography of a Naval Engineer* (Princeton, NJ: Princeton University Press, 1954), especially pages 177-78. Owens', "The Counterproductive Management of Science," is a thoughtful analysis of OSRD and its methods and limitations.

24 The literature of post-war celebration of OSRD is extensive. For its keynotes see James Phinney Baxter, 3rd, *Scientists Against Time* (Cambridge, MA: MIT Press, 1946); Vannevar Bush, *Modern Arms and Free Men: A Discussion of the Role of Science in Preserving Democracy* (Cambridge, MA: MIT Press, 1949).

25 Its "scientific" title notwithstanding, the OSRD was much more broadly technological than purely scientific in functioning and leadership. Bush himself was an engineer with an industrial as well as academic background, and indeed was one of the founders of what has become Raytheon Corp. See "Vannevar Bush," http://history.sandiego.edu/gen/WW2timeline/vannevar3.html; G. Pascal Zachary, *Endless Frontier: Vannevar Bush, Engineer of the American Century* (New York: Free Press, 1997).

Institution and chairman of the National Advisory Committee for Aeronautics (NACA). During this period, the Carnegie Institution was one of the largest funders of basic science in America and NACA, its name notwithstanding, was a major operating organization with its own laboratories and a leader in developing aeronautical technology for both military and civil applications.[26] These two posts put Bush at the absolute center of the American structures for S&T, rendering him familiar with and to every person and institution of importance, and with all the key technical subjects and issues.

Bush was accepted as a thoroughly "sound" member of the established elite, a man who could as easily strike a deal with President Roosevelt as with his predecessor and bitter political foe, Herbert Hoover (although Bush was personally much closer to "Great Engineer" Hoover). Eminent and financially secure, conservative, and little suspected of crass personal ambition, Bush brought a sense of high-minded public spiritedness to the NDRC/OSRD enterprise, and staffed its leadership positions with people of like mind. He was able to identify and draw on the talents of the most able scientific and academic administrators in the nation, and the very best S&T talent. He was a part of Roosevelt's extended circle and had access to him, greatly enhancing his authority.

Above all, OSRD benefitted from the strong national consensus regarding the importance of defeating Nazi Germany.[27] As an elite establishment traditionalist, Bush shared Roosevelt's aversion to bureaucracy and permanent structures that might become divorced from the immediate solution of particular and specific problems. As a result, Bush built OSRD on a network of ad hoc contractual relationships and committees staffed with top figures from the American S&T community, who were glad to take time away from their academic, institutional, or industrial responsibilities "for the duration of hostilities," that oversaw the contracts. The contracts did not call for definite products meeting definite specifications and they were usually written on a "best efforts" basis. This was a major innovation in federal contracting that would no doubt have been very difficult to implement in peacetime, but it was crucial to the operation of OSRD.

4. OSRD and Negotiated "Requirements"

This contract structure replaced the traditional pattern of imposed user "requirements" with negotiated agreements in which the developers had a strong voice. The ideal situation, from OSRD's standpoint, was that of the MIT Radiation Laboratory

[26] Alex Roland, *Model Research: The National Advisory Committee for Aeronautics, 1915-1958*, NASA SP-41031 (Washington, DC: National Aeronautics and Space Administration, 1985). The NACA was the direct ancestor of NASA.

[27] While Fascist Italy and Imperial Japan were also major members of the Axis, they were not generally perceived as falling in the same threat category as Nazi Germany.

or Rad Lab, which developed microwave radars that were critical to many phases of the war:

> A point which was stressed in [the Rad Lab's] relations with the Services was that the Army and Navy should not come to the Laboratory with technical problems for the design of a piece of equipment of specified dimensions and power requirements, but rather they should bring full information of the conditions of employment in which radar might aid, and provide full access by Laboratory personnel to information on the success or failure of various methods which had been tried. After acquiring an understanding of the military problem it was then the job of the technical people in the Laboratory to evolve suggestions and ideas for the best solution which they could visualize. The Laboratory then would come up with a proposal for the technical design of equipment, accompanied possibly by proposals for new methods of employment. After full analysis and discussion a final approach would be agreed on. From that time on the design of the equipment was left to the men in the Laboratory.[28]

Both the results and the recollections of Rad Lab veterans indicate that frustrations were remarkably low on both sides, considering what was at stake. There was no alternative source of microwave radars and the Radiation Laboratory undeniably provided outstanding results – better than what was achieved under more "normal" acquisition procedures after the war.[29]

OSRD's legacy includes a host of research groups of enduring importance like the Radiation Laboratory (the progenitor of the MIT Lincoln Laboratory, MITRE Corp., and a number of commercial offshoots), the Harvard Underwater Sound Laboratory (which became the Navy's Underwater Sound Lab in the post-war era), and the California Institute of Technology (Caltech's) rocket group (which spawned the Jet Propulsion Lab and the China Lake naval laboratory). And, as already noted, it established an image of highly competent "scientific" direction for defense R&D efforts. But by intent and nature it would leave no permanent structure. Its personnel drew down very quickly after the war ended, hesitating no longer than necessary to document the work done, and OSRD officially went out of business on the last day of 1947.

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[28] Stewart, *Organizing Scientific Research for War*, 163-64.

[29] Thomas Marschak, "The Role of Project Histories in the Study of R&D," in *Strategy for R&D: Studies in the Microeconomics of Development*, ed. Thomas Marschak, Thomas K. Glennan, Jr., and Robert Summers (New York: Springer-Verlag, 1987), 55-63, documents the problems of post-war radar development.

Figure 3. The Logo of the Radiation Laboratory at MIT

B. Post-war Drift

Even at its peak, very few envisioned that OSRD could or should continue much beyond the war's end. Indeed, Bush was dissuaded only by presidential directive from shutting much of it down well before the end.[30]

The performance of OSRD, together with the specter of German military technology, convinced nearly everyone involved that there had to be a major role for civilian scientists and technologists in postwar defense R&D efforts, but even within the Services there was considerable divergence of views about just how much this ought to be under independent civilian control and how much should be under the military chain of command.[31]

This intersected with a much wider debate about whether and how the federal government ought to pursue a broader S&T policy: Who would guide S&T? Who would fund it? How much was needed and to what ends?[32] Many believed – including Vannevar Bush – that defense S&T ought to be dealt with as an integral part of an overall national solution. But it never was possible to reach a consensus on an overall national solution, and even partial approaches were slow in coming.

In the meantime, the Army and Navy pursued their own courses. Their senior officers had almost uniformly come to the conclusion that technology was of vital importance. Many had come to believe that the course of advances in S&T needed to be determined with substantial input from experts in the field, but very few imagined

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30 Kevles, "Scientists, the Military, and the Control of Postwar Defense Research," 28, 33-35.

31 Ibid.

32 *Idem.*; Kevles, "The National Science Foundation and the Debate over Postwar Research Policy, 1942-1945: A Political Interpretation of Science—The Endless Frontier," *Isis* 68, no. 1 (Mar 1977): 4-26.

scientists or engineers should exercise authority over the choices of weapons, let alone military doctrine as Bush had advocated.

At the invitation of the Secretary of War and the Secretary of the Navy (SECNAV), Bush headed a Joint Research and Development Board that was supposed to help with coordination of R&D activities between Army and Navy. But the coordination was strictly voluntary and accomplished little. In the meantime, other prominent scientists and (more notably) engineers who were more willing to work under military leadership gained positions of influence (but little power) within the R&D structures of the Services.[33]

C. Unification: Halting First Steps

It was universally agreed that the lessons of World War II should be reflected in the post-war structures for national defense, but there was little consensus on what those lessons truly were, or how they should best be responded to.[34]

In 1944, even before the Normandy invasion, a Select Committee on Post-War Military Policy in the House of Representatives conducted a series of hearings, resulting in a request that the Joint Chiefs of Staff (JCS) study the issue of defense reorganization and make recommendations. The JCS formed a high-level committee but its members could not reach agreement – the Navy representative opposed formation of a single department of defense while the Army and Air Force officers supported it. Soon after the war's end in 1945, the Committee on Military Affairs of the Senate held three months of hearings, but proposals for unification again foundered due to adamant objections by the Navy, the Marine Corps, and their many supporters.

President Harry S. Truman, determined to pursue a reorganization of defense to eliminate, in his view, significant duplication and waste, sent a lengthy message to Congress on 19 December 1945. One section dealt specifically with scientific research for defense – which in context clearly meant what would today be called R&D:

> We should allocate systematically our limited resources for scientific research.
>
> No aspect of military preparedness is more important than scientific research. Given the limited amount of scientific talent that will be available for military purposes, we must systematically apply that talent to research in the most promising lines and on the weapons with the greatest

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33 Zachary, *Endless Frontier*, 312-21.

34 Except as otherwise noted, the narrative regarding the organizational development of defense in this chapter is based on Roger R. Trask and Alfred Goldberg, *The Department of Defense, 1947-1997: Organization and Leaders* (Washington, DC: Historical Office, Office of the Secretary of Defense, 1997), 1-31.

> potentiality, regardless of the Service in which these weapons will be used. We cannot afford to waste any of our scientific resources in duplication of effort.
>
> This does not mean that all Army and Navy laboratories would be immediately or even ultimately consolidated. The objective should be to preserve initiative and enterprise while eliminating duplication and misdirected effort. This can be accomplished only if we have an organizational structure which will permit fixing responsibility at the top for coordination among the Services.[35]

Nevertheless, it was 1947 before a compromise resulted in passage of the National Security Act of 1947 at the end of July. It established a separate Air Force under its own cabinet-level executive department and a Secretary of Defense (SECDEF) with authority of a very restricted nature over the three Services.[36] There was no executive Department of Defense (DOD), but the National Military Establishment (as it was termed) under the SECDEF included several statutory bodies in addition to the three military departments. One of these was the Research and Development Board (RDB), which the Act empowered as follows:

Research and Development Board

> Sec. 214. (a) There is hereby established in the National Military Establishment a Research and Development Board (hereinafter in this section referred to as the "Board"). The Board shall be composed of a Chairman, who shall be the head thereof, and two representatives from each of the Departments of the Army, Navy, and Air Force, to be designated by the Secretaries of their respective Departments. The Chairman shall be appointed from civilian life by the President, by and with the advice and consent of the Senate, and shall receive compensation at the rate of $14,000 a year. The purpose of the Board shall be to advise the Secretary of Defense as to the status of scientific research relative to the national security, and to assist him in assuring adequate provision for research and development on scientific problems relating to the national security.
>
> (b) It shall be the duty of the Board, under the direction of the Secretary of Defense—
>
> (1) to prepare a complete and integrated program of research and development for military purposes;

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35 This and other documents quoted here relating to the founding and organization of DOD may be found in Alice C. Cole et al., eds., *The Department of Defense: Documents on Establishment and Organization, 1944-1978* (Washington, DC: Historical Office, Office of the Secretary of Defense, 1978).

36 The Marine Corps did not gain full recognition as a separate fourth service until 1978.

> (2) to advise with regard to trends in scientific research relating to national security and the measures necessary to assure continued and increasing progress;
>
> (3) to recommend measures of coordination of research and development among the military departments, and allocation among them of responsibilities for specific programs of joint interest;
>
> (4) to formulate policy for the National Military Establishment in connection with research and development matters involving agencies outside the National Military Establishment;
>
> (5) to consider the interaction of research and development and strategy, and to advise the Joint Chiefs of Staff in connection therewith; and
>
> (6) to perform such other duties as the Secretary of Defense may direct.
>
> (c) When the Chairman of the Board first appointed has taken office the Joint Research and Development Board shall cease to exist and all its records and personnel shall be transferred to the Research and Development Board.
>
> (d) The Secretary of Defense shall provide the Board with such personnel and facilities as the Secretary may determine to be required by the Board for the performance of its functions.

Vannevar Bush was appointed the first chairman of the RDB. He attempted to run it in much the same manner as he had the World War II OSRD, but this was largely futile. Neither the chairman nor his boss, the SECDEF, had clear executive authority over Service R&D programs, let alone procurement. The SECDEF did have some budgetary authority and with sufficient bureaucratic deftness it might have been used to induce or compel some significant changes. But such methods were foreign to Bush's inclinations and experience.

In any event, anything effective would have required substantial SECDEF action, and SECDEF James V. Forrestal was overwhelmed with more urgent problems. In addition to the difficulties of establishing an entirely new institution for national defense, he had to contend with acute inter-Service conflicts, which had been greatly exacerbated (in an almost entirely unforeseen manner) by the National Security Act's provisions.

After a year Bush quit in frustration, leaving high office for the last time, still short of his sixtieth birthday.

Congress had severely constrained centralization in order to preserve its own power and prerogatives, as well as those of its Military Service clients. Indeed, Forrestal had been very active (as the SECNAV) in resisting centralization and even the whole notion of unification. But the inherent logic of executive power soon asserted itself, and while Forrestal struggled to overcome the constraints, even Congress could see the need for a stronger structure, prodded by continuing examples of wasteful duplication and internecine struggles.[37] Thus it proved grudgingly receptive when Truman, buttressed by the recommendations of a prestigious commission headed by former president Hoover, proposed modifications to the National Security Act, including the establishment of a full cabinet-level DOD. The 1949 amendments did little, however, to alter R&D management.

D. Cold War

The North Korean thrust across the 38th Parallel in June 1950, followed five months later by massive Chinese intervention, exerted an indirect but sharp galvanic effect on defense R&D – not because the war in Korea involved a great deal of advanced technology or a technologically sophisticated enemy, but because it was taken to signal a threat of aggression on the part of a unified international communist movement directed from Moscow. While this seems overblown in light of what is now known, intelligence on the Soviet Union was limited enough to make it seem all too plausible, particularly in light of the still-fresh memories of the 1930s, when discounting the threat posed by Hitler had proven to be very costly. Indeed, for many scientists who had bent great efforts toward Hitler's defeat, entering the lists again to prove their mettle against a vile new foe had some attractions of its own.[38]

Nuclear weapons aside, the exciting new technology of the period was the guided missile, and the Services had started about three dozen development programs. It was generally agreed that responsibilities and authority needed to be rationalized and a Director of Guided Missiles, a so-called Missile Czar, was set up in the Pentagon but with access to the president. The post was filled by, K.T. Keller, a tough auto-industry executive who was a confidante of President Truman. Although Keller lacked statutory authority, he was essentially empowered to borrow any authority he needed from the SECDEF. With a small, well-qualified staff he carefully reviewed each program and decreed its fate. Despite the inevitable grumbling from those whose favored programs were curtailed, there was general satisfaction with the result, which pointed to the benefits that more centralized authority over acquisition might bring.[39]

President Dwight D. Eisenhower was quite dissatisfied with the management of DOD and he submitted a DOD reorganization plan very shortly after assuming office in

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37 Elliott V. Converse, III, "Into the Cold War: An Overview of Acquisition in the Department of Defense, 1945-1958," in *Providing the Means of War: Historical Perspectives on Defense Acquisition, 1945-2000*, ed. Shannon A. Brown (Washington, DC: U.S. Army Center of Military History and Industrial College of the Armed Forces, 2005), 148.

38 Herbert F. York and G. Allen Greb, "Military Research and Development: A Postwar History," *Bulletin of the Atomic Scientists* 33, no. 1/2 (Jan 1977): 13-26, 17. York, who in 1959 was to become the first DDR&E, was active at high levels in this period.

39 York and Greb, "Military Research and Development," 18-19.

1953. Since it was politically difficult for Congress to resist his authority as an expert on defense matters, it agreed to his reorganization plan with minimal resistance. Among other things, he abolished the RDB and transferred its powers to the SECDEF. The SECDEF was provided with six additional assistant secretary billets. One was used to replace the chairman of the RDB but he had no more power than the RDB he replaced.[40]

E. Sputnik and the Establishment of DDR&E

The limited reforms of 1953 by no means met all of Eisenhower's goals for improvement, and several years of experience fully confirmed his belief that far more was needed. The opportunity came; however, from an unexpected quarter when, in October 1957 the public was startled and alarmed by the Soviet launch of the "Sputnik" satellite into low Earth orbit. Since World War II a large portion of Americans had believed that the cornerstone of national security was technological superiority and Sputnik was widely seen as a sign that it was slipping from America's grasp, if not already lost.

For the administration the resulting outcry was a both a challenge and an opportunity, and among the president's responses were proposals for the most sweeping changes in national security arrangements since 1947. Eisenhower took the occasion to greatly strengthen the scientific advice and oversight function in the White House, and moved to make fundamental changes in the Pentagon.[41] In an extraordinary and virtually unprecedented gesture he devoted much of his January 1958 State of the Union address to defense, including a call for DOD to "plan for a better integration of its defensive resources, particularly with respect to the newer weapons now building and under development. These obviously require full coordination in their development, production and use."[42] Emphasizing nuclear weapons and delivery systems – especially ballistic missiles – Eisenhower demanded that the SECDEF be given clear and undivided authority to direct R&D and assure the best possible use of S&T potential. As usual, Congress resisted expansion of executive authority, but the Sputnik launch had provided impetus to of the forces of centralization, at least where R&D was concerned.

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40 In principle, the RDB was succeeded by two ASDs, one for R&D and the other for "Applications Engineering." But it was never clear what the ASD(AE) was to do and it was filled with a retired executive who in fact did little. Eventually the post was abolished and the office was folded into that of the ASD(R&D). See York and Greb, "Military Research and Development," 20-21.

41 The White House changes and their effects are examined in York and Greb, "Military Research and Development," 22-23.

42 Quoted Converse, "Into the Cold War," 27.

1. The President's Message: A Manifesto

On 3 April 1958 the president transmitted a lengthy message to Congress detailing the changes he believed were necessary. He stressed that he considered it

> essential that the Secretary [of Defense]'s control over organization and funds be made complete and unchallengeable. … The Secretary must have full authority to prevent unwise service competition in this critical area. He needs authority to centralize, to the extent he deems necessary, selected research and development projects under his direct control in organizations that may be outside the military departments and to continue other activities within the military departments.[43]

He went on to propose a new high-level official, ranking above all the assistant secretaries, to be called the Director of Defense Research and Engineering (DDR&E), with three principal functions:

> First, to be the principal adviser to the Secretary of Defense on scientific and technical matters; second, to supervise all research and engineering activities in the Department of Defense, including those of the Advanced Research Projects Agency and of the Office of the Director of Guided Missiles; and, third, to direct research and engineering activities that require centralized management.
>
> Further, it will be his responsibility to plan research and development to meet the requirements of our national military objectives instead of the more limited requirements of each of the military services. … With the approval of the Secretary of Defense, this official will eliminate unpromising or unnecessarily duplicative programs, and release promising ones for development or production. An especially important duty will be to analyze the technical programs of the military departments to make sure that an integrated research and development program exists to cover the needs of each of the operational commands. It will be his responsibility to initiate projects to see that such gaps as may exist are filled. In addition, the Director will review assignments by the military departments to technical branches, bureaus, and laboratories to assure that the research and engineering activities of the Defense Department are efficiently managed and properly coordinated.
>
> Finally, I would charge the Director, under the direction of the Secretary of Defense, with seeing that unnecessary delays in the decision-making process are eliminated, that lead times are shortened, and that a steady flow of funds to approved programs is assured. Only under this kind of expert, single direction can the entire research and engineering effort be

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43 Alice C. Cole et al., eds., *Department of Defense: Documents on Establishment and Organization, 1944-1978* (Washington, DC: Historical Office, Office of the Secretary of Defense, 1978), 182-3.

substantially improved. In these various ways, he should help stop the service rivalries and self-serving publicity in this area.[44]

2. The Defense Reorganization Act of 1958

Congress was reluctant to grant such power to the Executive and took several months to agree at last on the details. The resulting bill included the following language:[45]

> Sec. 203. (b) (1) There shall be a Director of Defense Research and Engineering who shall be appointed from civilian life by the President, by and with the advice and consent of the Senate, who shall take precedence in the Department of Defense after the Secretary of Defense, the Deputy Secretary of Defense, the Secretary of the Army, the Secretary of the Navy, and the Secretary of the Air Force. The Director performs such duties with respect to research and engineering as the Secretary of Defense may prescribe, including, but not limited to, the following: (i) to be the principal adviser to the Secretary of Defense on scientific and technical matters; (ii) to supervise all research and engineering activities in the Department of Defense; and (iii) to direct and control (including their assignment or reassignment) research and engineering activities that the Secretary of Defense deems to require centralized management. The compensation of the Director is that prescribed by law for the Secretaries of the military departments.
>
> (2) The Secretary of Defense or his designee, subject to the approval of the President, is authorized to engage in basic and applied research projects essential to the responsibilities of the Department of Defense in the field of basic and applied research and development which pertain to weapons systems and other military requirements. The Secretary or his designee, subject to the approval of the President, is authorized to perform assigned research and development projects: by contract with private business entities, educational or research institutions, or other agencies of the Government, through one or more of the military departments, or by utilizing employees and consultants of the Department of Defense.

The new DDR&E organization emerged with the swearing in of its first director, Herbert F. York, on Christmas Eve of 1958. For the nearly two decades of its existence, the muscular statement of the April 1958 presidential message served as its de facto manifesto.

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44 Ibid., 183.

45 Defense Reorganization Act of 1958, 6 August 1958, 72 Stat. 514.

3. Research, Development, Test, and Evaluation (RDT&E) and Acquisition Budgets

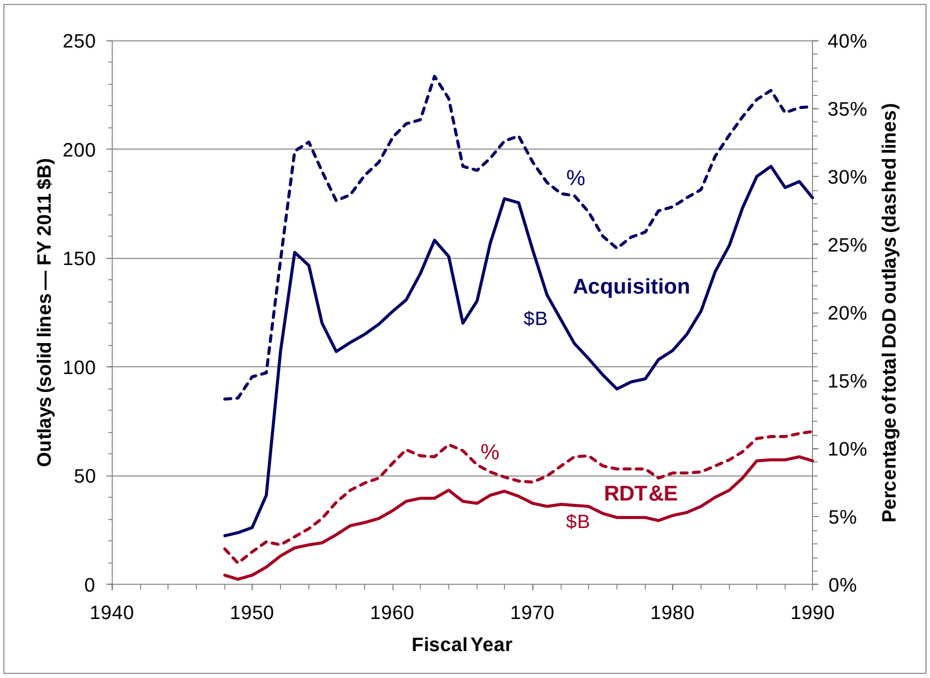

Figure 4. DOD Cold War RDT&E and Acquisition Outlays

DDR&E's direct statutory authority and responsibility extended over activities funded from various RDT&E (Research, Development, Test, and Evaluation) appropriations within DOD. But increasingly the need to manage acquisition – encompassing R&D, procurement, and direct support for them – as a unit was recognized, and with SECDEF encouragement DDR&E was took the lead in this, particularly in the 1970s. Thus in Figure 4 displays both the RDT&E and acquisition outlays across the period.[46]

DDR&Es sought, with general success, to urge that RDT&E spending be maintained at levels far higher than the historical norm. Through the first half of the 1970s, however, the amount of R&D declined as a result of both the post-Vietnam drawdown and the erosion resulting from high inflation, until the Carter and then the Reagan Administrations embarked on a major buildup in response to perceptions of a surging Soviet threat.

46 Plotted by O'Neil based on data drawn from Office of the Secretary of Defense (Comptroller), *National Defense Budget Estimates for FY 2011*, Mar 2010, (the "Green Book"), Table 6-11.

3. DDR&E's Operations in the 1960s

After some discussion, a formal charter that laid out the functions of the Office of the DDR&E was issued on 10 February 1959.[48] The charter provided that DDR&E would supervise all research and engineering activities in DOD; recommend a program of research and development to meet military requirements; recommend the assignment or reassignment of responsibility for the development of weapons; direct and control research activities that the secretary of defense considered to require centralized management; and recommend steps to provide for a more efficient and economical administration of research. He was empowered to conduct research through contracts with private organizations, through the military departments, or directly by using DOD employees, and to exercise administrative direction of the Weapons Systems Evaluation Group (WSEG).[49] He was instructed to consult with the JCS on the interaction of research and development with strategy.[50]

Director Herbert F. York absorbed the staff of the Assistant Secretary of Defense (Research and Engineering) and augmented it. In mid-1959 the personnel under him numbered 283, 203 civilians and 80 military. (This included the staff of WSEG, which probably numbered something like 50, largely military.) The Advanced Research Project Agency (ARPA) came directly under York later that year, adding its 48 civilians and 13 military personnel, for an overall total of 344 (251 civilian and 93 military).[51] A substantial portion of the civilians occupied Public Law 80-313 (P.L. 313) positions, with pay and prestige analogous to today's Senior Executive Service.[52]

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48 DOD Dir 5129.1, "Director of Defense Research and Engineering," 10 Feb 59.

49 WSEG had been established in 1948 to provide operational analyses and weapons systems evaluations for the JCS. It was abolished by SECDEF action in 1976. See John Ponturo, "Analytical Support for the Joint Chiefs of Staff: The WSEG Experience, 1948-1976," IDA Study S-507 (Alexandria, VA: Institute for Defense Analyses, July 1979).

50 Robert J. Watson, *Into the Missile Age, 1956-1960*, Volume IV of History of the Office of the Secretary of Defense, ed. Alfred Goldberg (Washington, DC: Historical Office of the Office of the Secretary of Defense, 1997), 288.

51 Ibid., 290, 362. ARPA had been established by executive action before the 1958 Reorganization Act that established DDR&E was passed. The agency has variously been called ARPA and DARPA (*Defense* ARPA) but for simplicity we will stick with ARPA in this paper.

52 Because it was virtually impossible to attract high-grade S&T personnel to positions at regular civil service grades of GS-15 and below, Congress in 1947 was persuaded to enact Public Law 80-313, 61

By 1968, the total DDR&E headcount reportedly had reached 558, including 177 military and 381 civilian, suggesting that the DDR&E staff had grown from approximately 280 in 1958 to perhaps as many as 400 or 450 in 1968.[53] Fifty-five of the civilians occupied P.L. 313 or managerial super grade (GS-16 through GS-18) positions. Of these top civilians, 86 percent held engineering or physical science degrees, 4 percent held degrees in non-technical subjects, and the remaining 10 percent had no degree. Most had industry backgrounds.[54]

SECDEF Melvin R. Laird (1969-1973) partially reversed the centralizing policies of SECDEF Robert McNamara, emphasizing what he termed “participatory management.” He and his immediate successors, Elliot L. Richardson (1973) and James R. Schlesinger (1973-1975) cut back the Office of the Secretary of Defense (OSD) staff in most areas, including DDR&E. Veterans of the DDR&E staff from this period recall having fewer than 150 technical people; the complete staff telephone directory fit on one 8"×10½" sheet.

A. From Massive Retaliation to Flexible Response and a Broadening of DDR&E

Atomic weapons – originally a product of the OSRD – dominated military thinking in the immediate post-war era. The weapons themselves were developed and built outside of DOD jurisdiction under non-military appropriations by the civilian Atomic Energy Commission (AEC).[55] The delivery systems and the systems to allow them to penetrate Soviet defenses and find their targets were a military responsibility. The Services saw them as simply weapons like other weapons, but of enormously greater power. But even the Services, which except for the Air Force, did not initially see them as central, all soon had their attention riveted by the overwhelming political attention that nuclear systems attracted. It seemed that nuclear forces were the key to gaining budgetary support and mission dominance. Thus each of the Services (other than the Marine Corps, which was not in fact recognized as a fully separate Service until much later) strove to gain its own share of nuclear forces.

Under such circumstances, it was only natural that DDR&E focus heavily on nuclear systems, including their delivery systems and necessary support. Indeed, each of

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Stat. 715, which allowed for a limited quota of “professional and scientific service” positions paid at higher rates. In much amended form it is codified as 5 U.S.C. §3104.

53 C. W. Borklund, *The Department of Defense* (New York: Frederick A. Praeger, Publishers, 1968), 83.

54 Richard Glenn Head, “Decision-Making on the A-7 Attack Aircraft Program” (Ph.D. diss, Syracuse University, 1970), 60.

55 Alice L. Buck, *A History of the Atomic Energy Commission*, DOE/ES-0003/1 (Washington, DC: U.S. Department of Energy, July 1983).

the first three men who occupied the office – York (1958-61), Harold Brown (1961-65), and John S. "Johnny" Foster, Jr. (1965-73) – was a physicist who had made his career in nuclear-weapons related research and been director of the Lawrence Livermore National Laboratory. During this period, the staff was also weighted in favor of experts in nuclear systems and missiles.

Those who studied issues of overall national strategy, however, had become sharply skeptical of the pervasive reliance on nuclear forces, seeing them as essentially unusable in most situations that might demand force or its threat. Thus while 1960 presidential candidate John F. Kennedy had run on a platform that stressed closing a supposed "missile gap," in 1961 President Kennedy insisted on a policy of "flexible response" as an alternative to the "massive retaliation" policy embraced, at least in principle, by his predecessor.[56] While the real meaning of this had to be worked out, it clearly portended an increased emphasis on conventional systems and at least a relative de-emphasis of nuclear ones.

The details of the policy were largely left to the new SECDEF, Robert S. McNamara (1961-68) and his top lieutenants, including DDR&E Harold Brown. This effort intersected with another of McNamara's principal thrusts, economy and efficiency in DOD. McNamara was a former Harvard business professor and major automobile industry executive who was widely regarded as an expert on efficiency in business (and, during his World War II Air Force service, in the military as well). To help spearhead the efficiency effort Charles J. Hitch, who headed the economics staff at the RAND Corporation and had studied defense operations and developed new ideas for improvement, was appointed Assistant Secretary of Defense (Comptroller). Hitch brought his protégé and former RAND colleague, Alain C. Enthoven, to head a newly-established analytical group known as the office of Systems Analysis (SA). SA and its successors have had a turbulent organizational history that included assuming a wide variety of levels and titles, while maintaining substantial continuity in function and personnel. This paper will refer to the office as SA during the 1960s and PA&E (Program Analysis and Evaluation) in the 1970s and 1980s.[57] While SA and its successors have played a role in acquisition decisions ever since 1961, the peak of its influence was under McNamara.

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56 The classic statement of "massive retaliation" is a speech by Secretary of State John Foster Dulles, printed as "Text of Dulles' Statement on Foreign Policy of Eisenhower Administration," *New York Times* (13 Jan 1954): 2. For the formulation of "flexible response" see Maxwell D. Taylor, *The Uncertain Trumpet* (New York: Harper and Row, 1960.)

57 The change in organizational titles actually became official in 1973, and the title varied slightly during the 1970s. In 2009 the organizational title became Cost and Program Evaluation (CAPE) as a result of the Weapon Systems Acquisition Reform Act of 2009.

B. DDR&E and Acquisition in the McNamara Era

One of McNamara's targets was what he saw as wasteful overlapping and duplication among the Services. This prompted his administration to advocate joint programs in acquisition so that Services with similar needs could buy the same system, rather than developing and procuring separate ones. Savings were expected in several ways: it should be cheaper, it seemed, to develop one system rather than two; if two or more Services bought the same system, it would bring economies of scale through larger production runs; and reducing the number of unique systems would simplify and economize on logistics.

When the commonality thrust was married to the Kennedy Administration's de-emphasis on nuclear forces, the result was a series of combined Air Force and Navy common aircraft programs. The first was the Navy's McDonnell Douglas F-4 Phantom II, which the Air Force was directed to procure in place of the Air Force-developed Republic F-105 Thunderchiefs that it would have preferred. Both of these aircraft belonged to a category the Air Force deemed tactical fighters, meaning aircraft that had good capabilities for air-to-air combat, interdiction strike, and close air support. In practice, however, the F-105 design had placed very heavy emphasis on strike with tactical nuclear weapons, to the detriment of capabilities in other mission areas.[58] In addition, it was a rather troublesome aircraft with high maintenance burdens and mediocre reliability.[59] As McNamara later explained to a top analyst on his staff, "I bought the F-4 because it was as good as the F-105 and gave us much more flexibility."[60] While there was Air Force resentment at having the F-4 forced upon them, the aircraft was well liked by operators and the Service continued to procure it for a number of years after McNamara left DOD. Because there were no significant technical issues, there was little DDR&E involvement in the F-4 decision; almost all of the staff work was undertaken by SA.

DDR&E was in the thick of the other two major common aircraft programs, the VAX or LTV A-7 Corsair II light attack aircraft and the TFX or F-111 tactical fighter. This paper will present the well-documented TFX/F-111 program as a case study in section D of this chapter.

Although nuclear and missile system programs continued to absorb much of the staff's attention, there were a variety of other tactical systems and technology programs with substantial DDR&E involvement. SA had called attention to the long closure times

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58 The "tactical nuclear weapon" was simply a nuclear weapon delivered with systems having a radius of no more than a few hundred miles.

59 Marcelle Size Knaack, *Post-World War II Fighters, 1945-1973*, vol. 1, Encyclopedia of US Air Force Aircraft and Missile Systems (Washington, DC: Office of Air Force History, 1978), 190-205. Cf *idem*, 264-85.

60 Head, "Decision-Making on the A-7," 164.

for U.S. forces in response to overseas contingencies as a result of old and limited airlift and sealift assets. Airlift was limited to some old propeller-driven, piston-engined transports with limited capacity, plus commercial aircraft from the Civil Reserve Air Fleet (CRAF) program, while sealift forces were all but nonexistent. The result was backing for the acquisition of a fleet of Lockheed C-141 medium jet airlifters, and acquisition of the new Lockheed C-5 heavy jet airlifter and a proposed force of Fast Deployment Logistics Ships.[61]

C. Acquisition Reform: Concept Formulation/Contract Definition/Development Planning and Total Package Procurement (TPP)

McNamara also moved to reform the acquisition system in major ways, as is described below.

It is conventional wisdom to take the memo signed by Deputy Secretary of Defense (DEPSECDEF) David Packard (1969-1971) on 28 May 1970 as the *fons et origo* of acquisition policy, but in reality its history extends back to the founding of the republic, and earlier. In particular, there was much more continuity between the policies of the McNamara administration and those of Packard and Laird than is ordinarily allowed.

The Armed Services Procurement Act of 1947 reiterated the traditional position that advertised bids (and thus fixed price contracts) were to be used whenever possible for DOD procurements, while allowing other contract forms when fixed price contracts were inappropriate.[62] The complex missile, weapons, and electronics systems programs of the later 1950s led to an explosive efflorescence of negotiated contracting, particularly in the Air Force. During this period cost growth in major Air Force weapon systems programs was typically on the order of 200 percent.[63]

Careful analysis – most notably by Harvard Business School authors Merton J. Peck and Frederic M. Scherer – suggested that this seemingly shocking result was very largely a consequence of basic structural factors that defied easy formulaic solutions, but then (as often since) "practical people" were impatient with such explanations and tended to

61 Although the Fast Deployment Logistics Ships program was cancelled due to Congressional concerns that it could lead to efforts to make the United States the "world's policeman," it was the precursor to the maritime prepositioning and fast sealift forces.

62 William Gates, "Department of Defense Procurement Policy Reform: An Evolutionary Perspective," NPS-54-89-01 (Monterey, California: Naval Postgraduate School, Jan 1989).

63 A[ndrew] W. Marshall and W[illiam] H. Meckling, "Predictability of the Costs, Time, and Success of Development," P-1821 (Santa Monica, CA: RAND Corp., 11 Dec 1959); Merton J. Peck and Frederic M. Scherer, *The Weapons Acquisition Process: An Economic Analysis* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1962), 19-25.

believe that a good dose of old-fashioned free market principles was what was needed.[64] This view became embodied as the "Charles Plan," after Robert H. Charles, Assistant Secretary of the Air Force (Installations and Logistics) (1963-1969), a lawyer with extensive aerospace industry executive experience. The Charles Plan soon became known as "Total Package Procurement" (TPP).[65] Under TPP a fixed price contract would be awarded at the outset covering the entire development and production of the new system, and as much as possible of the support.

In order to make TPP plausible it was essential to define at the outset exactly what was to be acquired. Indeed, it was the lack of any such definition that had earlier led to avoiding advertised bids for complex systems. This was the same issue that had led to the initial step away from advertised bids for aircraft in the Air Corps Act of 1926.

Thus, TPP required an elaboration and standardization of the front end of the acquisition process, embodied in DOD Directive 3200.9 of 1 Jul 1965, "Initiation of Engineering and Operational Systems Development" and the supporting DOD Directive 3200.6 of 7 Jun 1962, "Reporting of Research, Development and Engineering Program Information." The process – which had really evolved over the preceding decade in the Air Force – started with what was called *concept formulation*. During concept formulation OSD and the Service(s) involved assured themselves that they were buying the right system to meet real needs and that the technology was fully ready. The technology part might include research, exploratory development, and advanced development as appropriate, and was under DDR&E's oversight, while SA dealt with the analysis that picked the right alternative.

Once the technology risks had all been eliminated, the objective system had been completely defined, and the SECDEF had given formal approval (in what amounted to a milestone review and decision), the program moved to contract definition, which might proceed in as many as three phases. If there was doubt about which contractors might be qualified to compete for the program, Phase A winnowed the field. In Phase B several firms (usually three) received fixed-price contracts to definitize the contract design, specifications, and terms, ending in the submission of proposals to be evaluated in Phase C. For TPP the proposals would cover production and some support as well as development. Fixed-price incentive fee contracts were normally awarded for *operational system development* and production. (If TPP was not used there would be an *engineering*

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64 The classic analysis is Peck and Scherer's massive *The Weapons Acquisition Process*, much of which remains relevant and valid. It appears that they introduced or at least popularized the concept of *acquisition* as an integrated whole.

65 Except as noted, the source here for TPP is Albert J. Gravallese, "An Evaluation of the Total Package Procurement Concept As Exemplified By Three Air Force Weapon System Contracts" (M.S. thesis, Alfred P. Sloan School, MIT, 1968), supplemented in some details by Martin Meyerson, "Price of Admission Into the Defense Business," *Harvard Business Review* 45 (Jul-Aug 1967): 111-123.

development contract to be followed later by production contracts.) Execution of the contract would need SECDEF approval, as would the actual start of production.

This process attempted to greatly diminish the risk in weapons system acquisitions and to transfer the remaining risk to industry. McNamara had no personal experience in the defense industry, and Charles, who did, seems not to have clearly understood what he had experienced. Clear-sighted analysis of the technical and economic realities by their staffs – or a careful reading of the analysis already published by Peck and Scherer – would have revealed that this was not at all likely to work well. There is nothing in the record to suggest that such analyses were forthcoming from SA, Installations and Logistics, or DDR&E. We can only speculate about whether they would have had any effect on the decision makers if they had been.

In practice, the major TPP programs were all especially troubled and involved significant cost growth. In reaction, TPP was later explicitly denounced and rejected by Laird and Packard, although substantial elements of it have been tried repeatedly (and performed badly) in the years since then.[66]

But shorn of its connection to TPP, and variously adjusted and renamed, the general process of acquisition has not changed in half a century. That is, of course, one of the key reasons why lessons drawn from long-ago acquisition programs remain relevant to current and future challenges.

D. Case 1: TFX/F-111 Program

Our first case, the TFX/F-111 fighter acquisition, was one of the first major non-strategic programs with extensive DDR&E involvement.[67] It represents a baseline in more than one sense – no other program ever showed DDR&E in such a bad light or dragged it more deeply into controversy. It was also a major learning experience for the organization, and the memory of it lasted as long as the original DDR&E did.

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66 David L. McNicol, "Cost Growth in Major Weapon Procurement Programs, Second Edition," P-3832 (Alexandria, VA: Institute for Defense Analyses, 2005).

67 The two principal sources on the TFX/F-111 program are Robert J Art, *The TFX Decision: McNamara and the Military* (Boston: Little, Brown & Co., 1968); and Robert F. Coulam, *Illusions of Choice: The F-111 and the Problem of Weapons Acquisition Reform* (Princeton, NJ: Princeton University Press, 1977), which together form the primary basis for this. Much use also has been made of G. Keith Richey, "F-111 Systems Engineering Case Study," (Wright-Patterson AFB, Ohio: Center for Systems Engineering at the Air Force Institute of Technology, 10 March 2005, which inter alia summarizes many key points from Art and Coulam.

Figure 5. The Air Force Version of the F-111 in Flight

The TFX/F-111 came before Charles took office and was not a formal TPP program, but it had many of the same elements. In addition, it was a pioneering multi-Service development and like many pioneers, it wandered for a long time in a wilderness before emerging, much battered.

Harold Brown became DDR&E on 8 May 1961, 3½ months after McNamara's arrival as Secretary of Defense. The F-111 (then known as TFX) program was already in progress since on 16 February McNamara had directed the Services to study development of a new aircraft – a single common model – that would meet the Air Force requirement for a tactical fighter, the Navy's for a fleet air defense missile aircraft, and Army and Marine needs for a close-support aircraft. Brown said that the program began as

> a result of McNamara's desire to look at things from an across-the-board Department of Defense standpoint, so as to assure that where possible one did not have separate programs to do similar or even very different things if they could be done by a similar instrument. It really was not quite that clear at the beginning. It was not an instruction. It was something that evolved with time.[68]

1. Service Requirements

In any event, in important ways the program really had been going for several years before McNamara and Brown came to the Pentagon. The Air Force had been seeking a replacement for the F-105 since the late 1950s, and the Navy had been simultaneously pursuing a "missileer" aircraft with a powerful radar and long-range missile armament to defend the fleet against air attack. By early 1961 both Services had developed very

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[68] Harold Brown, recorded interview, 14 May 1964, 3, John F. Kennedy Library Oral History Program. Note that this series of interviews was recorded soon after the events, while Brown was still serving as DDR&E and while the F-111 development was still in progress.

strongly-held ideas about their needs, based in part on engineering and effectiveness analyses, and to a larger degree on internal negotiations among powerful groups and individuals. Both had come to the conclusion that their aircraft should use the then-new design feature of variable-sweep wings ("swing wings"), but otherwise there was not much similarity.

By a tactical fighter, the Air Force's Tactical Air Command (TAC) then meant an aircraft that could establish and maintain air superiority over the battle area, conduct interdiction strikes well beyond the forward line of troops, and conduct air-to-ground missions in direct support of troops. But in practice, TAC felt very strong political and doctrinal motivations to make the new aircraft especially capable of conducting low-altitude nuclear strikes deep into Warsaw Pact territory. That, in fact, was the special capability of the aircraft the TFX/F-111 was to replace, the F-105. But the TFX/F-111 was required to have much expanded capabilities. It was to carry a crew of two, be able to self-deploy unrefueled to Europe, operate from unimproved sod airstrips, reach Mach 2.5 at altitude, and penetrate 200 nautical miles at low altitudes at Mach 1.2 while carrying a nuclear payload.

The Navy, too, had a list of requirements. First, their aircraft needed to be able to operate from existing and planned aircraft carriers, implying a host of detailed engineering constraints, including some difficult to specify in advance.[69] Second, it had to carry not only a load of heavy missiles but a radar scanner four feet in diameter, with the two-man crew sitting side by side behind it in an escape capsule that permitted them to work safely in a shirt-sleeve environment while flying at high speed and high altitude. Third, in order to meet shipboard operation constraints, the length needed to be limited, and in conjunction with the bulk of a large radar dish and side-by-side seating this meant a relatively dumpy form, poorly suited for supersonic flight. Since the Navy did not see a need for supersonic speed, this was not a problem. But it ran counter to the Air Force's requirements for very high speed.

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69 For an overview of the criteria of carrier suitability as they were applied in the early stages of the F-35 Joint Strike Fighter program see Eric S. Ryberg, "The Influence of Ship Configuration on the Design of the Joint Strike Fighter" (Arlington: Joint Strike Fighter Program Office, 26 Feb 2002). Focus on such criteria tends however to obscure the point that the proof of carrier suitability lies in the Navy's testing, and that the criteria are only guides for early design. For the limits of the design criteria as guides see Thomas Rudowsky et al., "Review of the Carrier Approach Criteria for Carrier-Based Aircraft – Phase I: Final Report," TR-2002/71 (Patuxent River, MD: Naval Air Warfare Center, Aircraft Division, 10 Oct 2002). Naiveté regarding carrier suitability issues is one of the worst flaws of published analyses of the F-111 program, such as Coulam's otherwise excellent study, *Illusions of Choice.*

2. Requirements or *Desirements*?

It is useful to note that the F-111, as built and operated, fell far short of the Air Force's requirements for low-altitude dash, which involved flying for up to several hundred miles at very low altitude and supersonic speed. And it very rarely made any use of the Mach 2.5 top speed capability or the ability to operate from sod. Yet it, nevertheless, was always regarded as an especially capable and highly valuable strike asset. The complaints about it referred to its cost, reliability (especially in earlier series) and maintenance burdens, not its capabilities.

The Navy variant, the F-111B, was never procured. In its place the Navy developed the variable-sweep F-14A, using the same basic engines. The F-14A was also regarded very highly for its capabilities (but not its cost, reliability, or maintenance demands). Yet it, too, departed considerably from the original requirements for the F-111B, having a smaller radar dish, tandem seating, and separate ejection seats rather than an escape capsule.

The point is that these were not truly *requirements* at all, in the sense that they actually made a difference in national military capabilities worth paying what it would have cost to achieve them. Instead, they could better be described as *desirements* – agreed upon desires based on an internal negotiating process. After individuals who had been party to the negotiations left, they were no longer compelling.

And McNamara had his own requirement: 80 percent commonality by both parts and weight between Air Force and Navy variants. When asked about the rationale for a joint aircraft, DDR&E Harold Brown answered,

> By having a single development, one will (a) save quite a lot of development money, (b) and I think maybe this is more important, have a more common logistics system, and in so doing save quite a lot of money, because you will have a single production line, you will have in effect a single spare parts line, and divergence once started, of course, tends to continue. By keeping these things together, we may even someday be able to induce the services to take a common view for the purposes of aircraft.[70]

It should be noted that there is no mention here of an analysis to validate the existence or extent of these projected benefits, nor the tradeoffs that they might involve – the virtues were simply taken as a given and sufficient to justify joint acquisition. Other sources do nothing to change this picture: it appears that for one reason or another McNamara arrived with this view or formed it very early in 1961, and that he never asked for or received any critical analysis of it from his staff. So commonality was, in fact, also a desirement, not a rational requirement at all.

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[70] Ibid., 16.

It truly was an odd circumstance given McNamara's business background in the auto industry, with its multitude of models. No one had ever seriously suggested that there would be major benefits if the number of models of cars and trucks were to be slashed – that this might, for instance, allow prices to be reduced by enough to entice customers away from cars tailored to specific needs and preferences. But in defense it somehow seemed obvious, not only to McNamara but to many others, that commonality was so good an idea as to override all other considerations, so obvious, in fact, that no confirming analysis was needed.

Finally, there was little consistency between the Air Force's and McNamara's mission desirements. McNamara wanted the TFX/F-111, above all, to be a tactical fighter for genuinely tactical missions, a follow-on to the F-4. He had already curtailed F-105 procurement because it was less flexible than the F-4. Now the Air Force wanted to build an aircraft that was going, if anything, to be less flexible than the F-105.

3. The Unseeing Eye of DDR&E

The sum of the desirements, weighted by engineering realities, added up to severe program problems and high costs. Where was DOD's engineering watchdog, DDR&E?

Soon after his arrival, McNamara commissioned Brown to look at the commonality prospects, and Brown passed the order on to his staff. It appears that neither man left much doubt about the desired answer, but ultimately it was found that the close air support need could not realistically be met by a TFX that would satisfy the Services' desires for the principal missions. Contrary to the Service views, however, Brown and his staff decided that their remaining needs could be adequately fulfilled with a common design, and proceeded (under McNamara's direction) to compel a joint program, with the Air Force to take the lead in developing a largely common aircraft for both Services.

In his discussion of the issues associated with the program, Brown appears quite naïve, particularly about technical matters, and is sometimes quite wrong on the specifics – rather like someone who half digested briefings he did not understand in any depth. This stands in stark contrast to his discussions of strategic systems elsewhere in the series of 1964 interviews conducted by the Kennedy Library. On those topics he seems thoroughly well-informed and exhibits a good mastery of the issues.

This is consistent with the observations of at least two people who dealt with him directly on the Navy's version of TFX at the time. Admiral James S. Russell, U.S. Navy, who was the Vice Chief of Naval Operations at the start of the program in 1961, was a naval aviator and aeronautical engineer who reported being impressed with Brown's intelligence and energy. But he also saw him as an utter novice in aeronautical matters, and possessed of inappropriate confidence in dealing with them.[71] George A. Spangenberg, an aeronautical engineer and nationally known expert on aircraft design and integration issues, held a senior post in the Navy's aeronautical technical organization. He recorded an oral history of his impression of a meeting with Brown in September 1961:

> Dr. Brown was supposed to chair the meeting and he was twenty to thirty minutes late in getting there. He walked in followed by a half dozen of his staff and so on. His first words were after looking around the room and seeing no military uniforms, "Well, what have they done to us now." He was obviously referring to the military. Those were the first words I had ever heard from Dr. Brown directly and it didn't enhance my opinion of him at that time. My opinion really hasn't changed over the years that he might have been a fine nuclear physicist but he sure didn't know airplanes, nor the aircraft acquisition process.[72]

It seems clear that Brown did not appreciate the very strict demands that an aircraft had to meet in order to operate successfully from aircraft carriers. He would have been aware that the F-4 was adjudged suitable for use by both the Navy and Air Force, and perhaps he knew that some other aircraft had also passed the test for joint use. But the only jet aircraft to perform successfully in both roles up to that time had originally been developed specifically for naval use and later adapted for Air Force employment.[73]

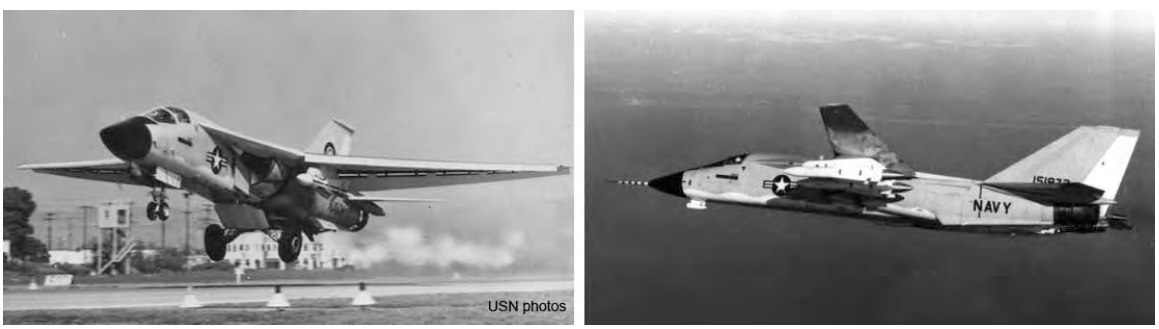

Figure 6. The Navy Variant, the F-111B, in Tests

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71 Admiral Russell was a family friend of O'Neil (principal author of this study), who had many conversations with him on the subject in the late 1960s and through the 1970s.

72 George A. Spangenberg, oral history transcript, 217, http://www.georgespangenberg.com/gasoralhistory.pdf.

73 A limited partial exception was the Air Force's North American F-86 fighter, which was successfully adapted for naval service as the FJ-2, -3, and -4. It, however, had originally been developed on the basis of the Navy's FJ-1, albeit much modified in the process. France later successfully developed a joint navy-air force fighter, the Dassault Rafale, in the 1980s and 1990s, with neither service in the lead. The international F-35 Joint Strike Fighter is proceeding on a completely joint basis, but has become a notably troubled program.

Therefore, DDR&E's insistence (perhaps echoing McNamara) that the F-111 program be conducted essentially as an Air Force development, with only peripheral Navy involvement compounded the problem. If the Navy had been given more control and more responsibility for the program the chances of success would have been better – it would surely have taken more ownership and responsibility, and very likely would have been able to find more workable technical solutions. Yet there is no indication that this was ever considered by DDR&E.

In addition to the problems associated with the plans for Navy-Air Force commonality, the program suffered from the fundamental disjunction between the Air Force's plans and McNamara's desires regarding the plane's mission, and the extreme technical demands implied by the Air Force's requirements, especially flying long distances at low altitude at high transonic speeds.

According to a thorough study conducted in the early 1970s, it was DDR&E that spearheaded the drive to forge a common program. According to the study, SA, still in its naissance, deliberately stayed away from the issue.[74] There is no indication that DDR&E ever warned of the serious program and cost problems raised by the requirement for high commonality, even though these problems were acutely apparent to the technical participants. Nor does DDR&E appear to have adequately probed the problems involved in meeting the aircraft's basic performance requirements.

Finally, it appears that no one pointed out to McNamara that the concept formulation efforts were all pointed not toward an all-purpose tactical fighter as he wished but a nuclear bomber. In all of these matters DDR&E fell seriously short. In addition, DDR&E failed to call attention to the problems inherent in the way that the acquisition program was structured. Technically, this was not DDR&E's responsibility at that point, but someone needed to take responsibility and in principle DDR&E should have been more aware of the realities of defense industry operations and economics than any other group in OSD.

In essence, the organization found itself in a situation it was not well prepared for. A very strong-minded SECDEF had turned to a very young (thirty-three years of age when he took office), newly-appointed DDR&E and charged him to "get it done." Brown did not know nearly enough to frame and present any compelling dissent or reservation and it is questionable whether he had enough credibility with McNamara at that time to have successfully argued his point if he had.

We know little of what role the DDR&E staff played. If there were engineers on the staff with experience in developing tactical aircraft, including carrier-based aircraft, or engineers with a good basic background in aircraft had closely queried those who had

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74 Coulam, *Illusions of Choice*, 108-11.

such experience, what was likely to be involved and what kinds of problems might emerge would have been more apparent. According to interviews with a Congressional staff member and an unnamed DDR&E official, the staff was "dominated by men with backgrounds in the technologies of guided missiles and electronics."[75] While people with extensive aircraft backgrounds eventually joined DDR&E, apparently none were on the staff at this point. In any event, if there were staff members with qualms about the drive to commonality, they appear to have failed to take them to Brown.

By its actions and lack of action, DDR&E had contributed to the high costs, technical deficiencies, and mission limitations of the F-111. Moreover, it had undermined its own credibility.

4. Digital Avionics

DDR&E played a major role in another aspect of the program, also with problematic results. The avionics system of the basic version of the F-111A aircraft was adequate for all-weather, low-precision, delivery of nuclear weapons against pre-assigned targets, but did not permit precision conventional weapons delivery over a range of tactical situations. Digital systems were advancing rapidly, and members of the DDR&E staff believed that a much more capable, largely digital system was within reach. With support from sources like the President's Science Advisor and the Air Force's own Science Advisory Board, they had little difficulty convincing Brown and ultimately McNamara to put pressure on a somewhat reluctant Air Force to develop a new system for installation in an F-111D model that was supposed to become the major production version.[76]

In theory there was nothing inherently wrong with pressing the development of a new avionics system. But in practical terms, it was defective; it did not achieve its intended objective effectively; and it had serious unforeseen consequences that were not probed adequately in advance.

In principle the avionics issue played to the staff's strengths in electronics. What was proposed for the system was not unreasonable in itself and, indeed, systems capable of similar functions soon became common.[77] The problem was not in the underlying technology but in the lack of full understanding of what was involved in implementing a system. While the DDR&E staff could not reasonably have foreseen the specific problems, by 1965 there was sufficient experience with the new complex digital electronics systems to have counseled caution about schedules and costs. In particular, it

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[75] Coulam, *Illusions of Choice*, 128.

[76] "Case Study: The Mark II Avionics System," Acquisition History Project Working Paper #4, http://www.history.army.mil/acquisition/research/working4.html.

[77] The trouble-plagued effort on the F-111D avionics was a major learning experience for the industry and contributed to the development of better systems soon thereafter.

was already amply clear that the interface timing and feedback problems of real-time systems could be very difficult to resolve and that this contributed substantial uncertainties about the hardware and particularly the software effort.[78] It would be illuminating to know to what extent the DDR&E staff's experience had been in digital systems (as contrasted with the older analogue systems, whose problems were better understood), but this information does not seem to be available.

Another problematic aspect of DDR&E's involvement in the TFX/F-111 was the effect it had on relations with SA. Of the same avionics effort (but in connection with the A-7 rather than the F-111), the senior SA official, Russell Murray, II, who dealt with tactical programs, told a researcher that it had come about because of

> Gadgeteers. Gadgeteers. I think it is gadgeteers; it is what happens to every airplane.… Pretty soon your nice, simple little airplane has everyone's favorite gadget on it, and the cost is doubled; how did that happen? Well, it's all this junk that keeps getting put on there. Now it's not all junk, but the difficulty is that people have high hopes for their latest invention. So instead of taking it out and testing it and demonstrating that it really will work under realistic conditions and then putting it in, they say, "No, that'd take too long; we'd miss half of the production. We better put it in at the beginning." And that's what happens.[79]

Murray was always particularly outspoken, and given to colorful expression, but there is no doubt that in substance he spoke for SA generally. And as he had a master's of science in aeronautical engineering and substantial aircraft industry experience, his views can scarcely be dismissed as the mouthings of a naïf. Ultimately, of course, the pursuit of avionics advances did bring worthwhile improvements in combat effectiveness in many areas, but it is not clear that Murray's more measured approach would have done much if anything to slow progress. In the meantime, DDR&E advocacy of early commitment and deployment accomplished little, wasted resources, and created tensions with SA/PA&E.

E. Case 2: Missile Defense Alarm System (MIDAS) and Defense Support Program (DSP)

While the TFX/F-111 is perhaps the most widely known example of DDR&E's 1960s involvement, it is far from typical. A considerable portion of DDR&E's effort was directed toward sensor systems, and particularly surveillance and acquisition sensors – systems that search for targets of a particular class against a background that makes it

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78 A real-time system must interact with and respond to a stream of events in a complex environment that it does not control. O'Neil had experience with such systems early in the 1960s and heard (and issued) many cautions about the problems involved in their development several years before the events discussed here.

79 Head, "Decision-Making on the A-7," 388. Murray was later the head of PA&E.

difficult to distinguish valid targets. The details of most of these programs are highly classified, so we cannot present cases. But the MIDAS and follow-on DSP efforts were open enough to leave a meaningful written record.[80]

All surveillance and acquisition sensor programs deal with four classes of issues:

- Phenomenology of the detection signature emitted or modulated by the target.
- Phenomenology of the interference and background signatures.
- Design of the computational/processing scheme to distinguish detection signatures.
- Design of the hardware to implement the sensor itself, the processing system, and supporting systems.

All of these issues must be assessed using the most plausible, worst case, adverse scenarios, especially involving hostile efforts to interfere with or degrade the sensor system.

There is never information enough to fully and accurately assess these factors at the outset of a new program. At this stage the planning fallacy often operates with special force to mislead those who conceive a new sensor about its real prospects.[81] It is essential to analyze the issues objectively and to frame a program of measurement, test, and simulation to resolve them efficiently.[82] It is often difficult for those who have become enthusiastic about the potential of a new sensor concept to recognize this. Of course it is important to get an accurate understanding before committing full resources so that cost-effectiveness can be realistically assessed.

MIDAS and DSP were conceived as space-borne infrared (IR) sensors that would watch the earth below for the signatures of rocket engine exhausts high above the sensible atmosphere in order to provide warning of ballistic missiles boosting toward the United States or other locations of defense concern. Such schemes were first proposed and seriously studied in the mid-1950s, before anything had been launched into orbit. Driven by Central Intelligence Agency warnings of early deployment of Soviet intercontinental ballistic missiles (ICBMs), the Air Force and ARPA joined at the end of

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[80] MIDAS and DSP carried a variety of other designations, but we will stick to the best known.

[81] Regarding the planning fallacy and some of its implications see Roger Buehler, Dale Griffin, and Johanna Peetz, “The Planning Fallacy: Cognitive, Motivational, and Social Origins,” *Advances in Experimental Social Psychology* 43 (Jul 2010): 1-62.

[82] As an example, it was observance of this principle that allowed the British to develop effective radar systems in the last few years prior to World War II, while the Germans consistently lagged behind the Allies due to their neglect of it, notwithstanding having begun from a superior basic technology base. See S[ean] S. Swords, *Technical History of the Beginnings of RADAR*, ed. Brian Bowers, vol. 6, IEE History of Technology Series (London: Peter Peregrinus, 1986).

1958 to define the MIDAS program. The following February the Air Force submitted a development plan aimed at achieving an initial operational capability by mid-1961.[83]

The principle of IR satellites for ICBM warning commanded support at the highest levels, but the plans for immediate operational deployment were received coolly. Tests were pressed forward, but DDR&E was concerned that rushing to deployment would be wasteful and insisted that work remain focused on resolving the basic issues rather than aiming at early deployment. Throughout this period there were dueling high-level review panels and studies. Indeed, Harold Brown's introduction to the program had come before his appointment as DDR&E, when he sat on one of the first review panels. Once in office, he commissioned several panels of outside experts, supported by his staff, to probe the uncertainties and stress the need for more information before an operational system could be contemplated. The Air Force pushed back with panels of its own criticizing these critiques and recommending urgency in deploying an operational system.

DDR&E could not be moved off its determination to establish an adequate base of research first, with deployment efforts to be deferred. The Air Force tried to avoid some important steps in the research process, but the DDR&E staff alerted Brown, who reproved them as necessary. The Air Force pointed to forecasts of a massive Soviet buildup of ICBMs (which did not in fact materialize), but DDR&E countered with other ideas that could fill the gap more surely and quickly if the threat occurred. These included airborne IR sensors (which would need less angular discrimination due to the shorter range and less sensitivity because they would see targets against a sky background) and over-the-horizon radars (OTHRs) (which were used to track Soviet missile tests).

In fact, the first six MIDAS launches were failures or short-lived partial successes. It was not until mid-1962 that there was a sensor system with real potential, and it took another year to get a satellite up that was able to demonstrate the potential. After another launch failure, the next satellite, the ninth, worked long enough to confirm the results that had been demonstrated by the successful test satellite.

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83 Jeffrey T. Richelson, *America's Space Sentinels: DSP Satellites and National Security* (Lawrence, KS: University Press of Kansas, 1999) provides an extended narrative of the MIDAS and DSP, and their antecedents. This was later supplemented with a collection of original documents posted by Richelson on the World Wide Web at http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB235/index.htm. These have been the principal sources for this case study, together with Brown's oral history interviews, supplemented in a few areas by O'Neil's recollections of discussions with DDR&E/USDRE colleagues working on DSP in the 1970s and early 1980s.

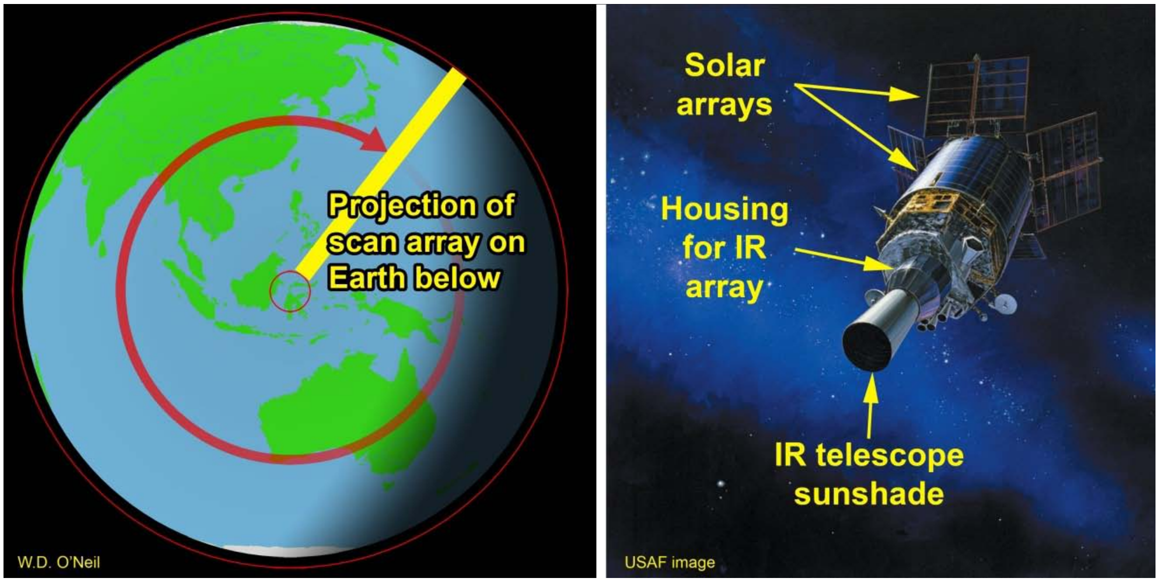

Figure 7. The DSP: Diagram of the Scan (left) and Impression of the Spacecraft (right)

After the successful demonstration of basic feasibility by the autumn of 1963, the inquiry shifted to cost-effectiveness. Although SA also weighed in, here too Brown and his DDR&E staff took the lead. The question was not a simple one. As noted, there were other existing and potential sources of missile launch warning. They could not do all that an IR overhead system might, but how much was the added capability worth? Since the idea had originally been conceived, the United States had developed a strategic posture that was far more robust and able to ride out an attack without a crippling loss of retaliatory capacity, thus lessening the urgency for getting the earliest possible warning. Much to Air Force annoyance, Brown insisted on refining the system and expanding its capabilities for other missions, such as attack characterization, nuclear detonation detection, and technical intelligence before going ahead.

Plans were developed that satisfied DDR&E and a much improved and modified system, now called DSP (a deliberately nondescript code name) began operational deployment in 1970. DDR&E involvement continued at a lower level as development was scaled back and focused on system improvements in response to technology opportunities and shifting strategic needs. One disagreement arose in 1979 over an Air Force proposal for an Advanced Warning System that would incorporate a step-stare sensor featuring a mosaic of two-dimensional focal plane arrays rather than the scanning sensor used by DSP. This initially seemed attractive, but the USDRE staff concluded that the risks of the mosaic sensor were too high to commit to it at that point. They won the argument and the mosaic sensor remained in test. It was a number of years later before sensors of this type emerged as practical for applications similar to DSP.

In retrospect it is clear that while DDR&E was not right about everything, it saw most issues quite clearly and moved decisively to keep IR warning satellite development on track and moving productively. Without DDR&E intervention it seems very likely that the program would have become mired in premature efforts to deploy inadequate technology. The schedule that DDR&E drove was probably approximately optimal.

An apologist for the Air Force position might suggest, as the Air Force did at the time, that if the Soviet ICBM threat had, in fact, developed as rapidly as was forecast in the 1960s it would have been better to have even a costly and immature warning system. But as DDR&E pointed out at the time, there were other alternatives for warning that could be deployed much more rapidly and with much better assurance of success, if it had been proven necessary. The IR warning satellite made sense as a moderate-risk, moderate-cost system, but would not have as a high-risk, high-cost system.

The subsequent history of the intended DSP replacement, the High-orbit Space-Based IR System (SBIRS High) provides a useful yardstick for the accomplishment of DDR&E in guiding MIDAS and DSP. Conceived as an "acquisition reform" model program in which the influence of OSD would be minimal, the cost of the SBIRS High is now expected to be about triple what was originally planned, and development has so far run well over twice as long as planned – enough of a slip to raise concerns about maintaining the integrity of the nation's launch warning capabilities. And the first operational satellite has yet to reach the launch pad, let alone orbit.[84]

In the MIDAS/DSP case we see a service acquisition agency, driven by operational user demands, pushing hard to develop and deploy an operational system very rapidly at a point where many major uncertainties remained unresolved. It was a common situation then and remains so today. Under a number of leaders (York, Brown, Foster, and Perry) DDR&E/USDRE insisted that issues had to be resolved thorough basic engineering before proceeding to an operational system. The Air Force complained very loudly that DDR&E and later USDRE were delaying an urgently-needed capability – another situation familiar today. But the record shows clearly that they did not delay achievement of a genuine operational capability through their direction. Indeed, it seems very likely that plunging into full development and deployment, as urged by the Air Force, would have resulted not only in a great deal of waste but probably delay in achieving an actual capability, due to the crowding out of basic engineering tasks.

DDR&E and USDRE were able to prevail because they had leaders who had a sound grasp of the issues involved in the system and its use, who were supported by knowledgeable and effective staff, and worked under SECDEFs who were able to recognize the value and importance of the advice they received from DDR&E and

84 For more on this troubled program see William D. O'Neil, "Space Based Infrared System," Appendix J of *The Major Causes of Cost Growth in Defense Acquisition – Volume III: Appendixes*, by Gene Porter, et al, IDA Paper P-4531 (Alexandria, VA: Institute for Defense Analyses, Dec 2009) (For Official Use Only). Still further slippage has been announced since that analysis was completed.

USDRE. The effectiveness of the staff was enhanced by informal contacts with technical people in the Air Force and outside groups who were willing to discuss important technical issues frankly, even when they did not support authoritative Service positions. And there was no conflict with the other major officials in OSD regarding the course to be followed, nor with the Congress.

In contrast to the TFX/F-111, which eroded DDR&E's image and authority, the case of MIDAS/DSP upheld and even enhanced it.

F. Other DDR&E Efforts in the McNamara Era

Both the MIDAS/DSP and TFX/F-111 seem in many ways to exemplify and reflect larger patterns. Particularly in the first few years of Robert McNamara's tenure at DOD, his efforts to redirect nuclear strategy led to a wide range of acquisition actions, like MIDAS/DSP, relating to nuclear delivery and defense. This was Harold Brown's strength and he and his staff were effective in developing the strategy and carrying through its acquisition aspects, often against resistance from the Services.

Non-nuclear related acquisition programs often played to DDR&E weaknesses rather than its strengths, however. Prior to Malcolm R. "Mal" Currie, who succeeded Foster as DDR&E in June 1973, no occupant of the post had any substantial direct experience with tactical logistics or electronics systems, nor with major acquisition programs generally. Currie was also the first DDR&E with an industry background. During Foster's tenure from 1965 to 1973, managers and staff members with industry backgrounds were brought in and Foster developed a good deal of personal mastery in these areas, but this came largely after McNamara's departure at the end of February 1968. In the meantime, McNamara's administration faced significant acquisition problems that DDR&E appears to have done little if anything to avert.

The most notable was the C-5A program, with Lockheed selected as prime contractor. The C-5 lacked major technology issues, unlike the F-111, and that appears to have led to a lack of DDR&E involvement. But the design issues resulting from its unprecedented size, combined with a total package procurement (TPP) acquisition strategy, caused great problems. The result was major cost growth, a serious threat to the health of an important defense contractor, and significant defects in the aircraft.

Even in shipbuilding, where technical risks were lower still, the McNamara era TPP acquisition approach led to major problems in the LHA amphibious assault ship and, to a lesser extent, DX/DD 963 destroyer programs. Again, it appears that DDR&E was largely uninvolved.

DDR&E had more involvement in the joint U.S.-German MBT-70 program which sought to develop a largely common tank to be built and deployed by both nations. DDR&E did not recognize the extent of the U.S. Army's pursuit of high-risk technologies as part of what was supposed to be an engineering development program, and was not very effective in helping to ensure that the partners worked effectively together. Eventually Congress killed the effort, leading eventually to the more successful M-1 Abrams tank program.

DDR&E involvement was greater in the F-X program that became the McDonnell Douglas F-15 fighter for the Air Force. The design concept initiative came from a group of enthusiasts, associated with Air Force Colonel John R. Boyd, who called themselves the "fighter mafia." Initially, DDR&E insisted on a multipurpose aircraft, common with the Navy. This was a recipe for another F-111 and eventually Air Force arguments in favor of a pure fighter with a focus on air superiority prevailed, in part because the Air Force had gone along with OSD insistence that it adopt the Navy's A-7 for ground attack missions. The Air Force's position was bolstered by the fact that Harold Brown had moved from DDR&E to take over as Secretary of the Air Force and strongly supported his new organization's position.[85]

As late as mid-1969, Foster had insisted that the new program be a total package procurement, before finally withdrawing his objection to the Air Force's plans for a cost-plus-incentive development only when his hand was forced by Packard's denunciation of TPP as a policy.[86] More constructively, he persistently pressed the Air Force to look hard at measures to reduce the procurement cost of the aircraft. The reasons for Foster's late attachment to TPP are not clear, but his own lack of large-scale acquisition experience may have led him to be less sensitive to TPP's underlying problems.

G. Vietnam and Relations with the Military

During the Vietnam War, DDR&E played an active role in the management and oversight of a number of efforts to develop solutions to the problems that emerged and it also exerted considerable influence over future directions for development.

DDR&E had only late and peripheral involvement in the war's most famous (or infamous) technological effort, Operation Ranch Hand, which used existing spraying systems to spread commercial defoliants on heavily vegetated areas to reduce opportunities for enemy cover. Using its ability to draw on outside scientific advice,

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85 Jacob Neufeld, "The F-15 Eagle: Origins and Development, 1964-1972," *Air Power History* 48, no. 1 (Spring 2001): 4-21.

86 Neufeld, "The F-15 Eagle," 14, citing a memo from Foster to the Secretary of the Air Force, subj. "F-15 Procurement Considerations," 13 May 1969, as well as another memo on "F-15 Acquisition," 11 Jun 1969.

DDR&E evaluated and responded to the environmental concerns, eventually recommending eliminating the use of the controversial AGENT ORANGE.[87]

DDR&E's involvement was much more extensive in the other very visible and controversial technological operation, known informally as the "McNamara Line," which employed a variety of electronic sensors to target North Vietnamese efforts to infiltrate South Vietnam with troops and supplies. It was recognized from the outset that such a barrier would be subjected to a wide variety of enemy efforts to counter and circumvent it and that it would not be air tight. Nonetheless, the sensors were credited with being highly effective as a key element in the defense of isolated outposts such as Khe Sanh. And they made it possible to inflict very substantial casualties on infiltrating forces. But they could not provide complete coverage of the vast and rugged "Ho Chi Minh Trail" region.[88]

Many of the Vietnam-related efforts were related to special electronic equipment for communications, sensing, or electronic warfare. The electronic warfare systems played a particularly prominent role as U.S. Air Force and Navy aircraft strove to neutralize increasingly strong North Vietnamese air defenses. Here, DDR&E took a very active role in stimulating, guiding, and coordinating efforts by a variety of Service and industry groups that produced effective countermeasures systems.

The Vietnam experience had a significant effect on some of the principal technological thrusts of the era. It prompted wholesale change in the approaches to the suppression of enemy air defenses and aircraft survivability. It brought increased urgency to the development of precision air-to-ground weapon delivery. But beyond these and other specifics, Vietnam exerted an effect on thinking about defense needs generally. While some attributed failures in Vietnam to a lack of political will, in the eyes of others they reflected directly on military doctrine, hardware choices, and overall thinking. While few in the defense community may have shared in the broad disillusionment with authority that spread through American society, some came to question "authoritative" views on military needs and requirements. Many in DDR&E shared some of this feeling.

The first three leaders of DDR&E, York, Brown, and Foster, were all noted scientific experts on nuclear weapons before they came to the job. Like a great many men from their community, they believed (with considerable justification) that they knew as much (or little) about nuclear war as anyone, and were not particularly in awe of military expertise. They were prepared to work productively with competent military officers

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87 William A. Buckingham, Jr., *Operation Ranch Hand: The Air Force and Herbicides in Southeast Asia, 1961-1971* (Washington, DC: Office of Air Force History, 1982), 139, 157-8, 166, and 182.

88 John T. Correll, "Igloo White," *Air Force Magazine* (Nov 2004): 56-61; Bernard C. Nalty, *The War Against Trucks: Aerial Interdiction in Southern Laos, 1968-1972* (Washington, DC: Air Force History and Museums Program, 2005).

based on mutual understanding and respect, but not to defer to their authority. Some saw this as "arrogance," and others saw it as reasonable self-confidence and assertiveness.

The competence to carry off such a posture successfully did not extend, however, uniformly throughout the DDR&E organization of the 1960s. Outside of the strategic warfare fields, expertise was spotty, and deference to the expertise of the Military Services would have been an understandable cultural norm, particularly among junior military officers on the staff and civilians who had begun their careers in the Service laboratories.

Shortly after Foster took over as DDR&E, he brought in Charles A. "Bert" Fowler to be his Deputy Director for Tactical Warfare Programs (DD(TWP)). Fowler was a prominent radar expert who had worked in the MIT Radiation Laboratory that had played the central role in microwave radar development in World War II. Later he had joined the Radiation Laboratory's successor, MIT Lincoln Laboratory, then moved to Airborne Instruments Laboratory, another offshoot of the wartime OSRD. After accompanying Foster on an inspection trip to South Vietnam in 1968, Fowler devised a scheme to adapt an existing moving target indication radar for helicopter operation in order to provide real-time detection and tracking of enemy troop movements.[89] The Army was unresponsive to his demand to deploy such systems on an urgent basis. But he did eventually foster development of a prototype that was very well received when it participated in NATO exercises in Europe, and ultimately led (by a somewhat circuitous route) to the development of the successful E-8 JSTARS airborne radar system for detecting and tracking ground movements. It was a foretaste of much to come.

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89 A moving target indication radar utilizes the Doppler of the return signal (the proportional difference between its frequency and that of the transmitted pulse) to identify targets that have a component of motion toward or away from the radar along the line of sight. It is a pulsed radar that can measure target position but is unable to provide unambiguous measurements of the magnitude of the motion. In essence it operates by cancelling out low-Doppler fixed returns. See Merrill I. Skolnik, *Introduction to Radar Systems*, Third ed. (Boston: McGraw-Hill, 2001), 104 *et seq*.

4. DDR&E from 1969 through 1976

A. The Packard Acquisition Policies

1969 brought a new administration to the White House and DOD. John Foster remained in office as the DDR&E for another four years, but the crucial job of DEPSECDEF was occupied until the end of 1971 by David Packard, a prominent engineering entrepreneur who took a particularly keen interest in acquisition. (His immediate successor, Kenneth Rush, presented a marked contrast. As an attorney and former top mining company executive whose interests were primarily in diplomacy, Rush served less than a year in DOD between top diplomatic posts.)

The political opposition to McNamara and the Vietnam War appeared to have fostered an especially critical view of DOD and its operations in general – acquisition included – by the press, public, and Congress. While acquisition performance in the 1960s was perhaps no worse than it had been in the 1950s, it also seemed no better and it certainly had not lived up to the promise of the McNamara reforms. Concern about cost growth was heightened by the defense budget reductions that accompanied the drawdown of forces from Vietnam.

Beginning shortly after the inauguration of the new administration and continuing throughout out his tenure, Packard produced a number of new and modified policies for acquisition. Although most accounts overstate the extent to which they broke from earlier stated policies, there is no question that the Packard reforms set the overall pattern of acquisition management that has persisted in increasingly elaborated form ever since.

In a 1971 article in the *Defense Management Journal*, Packard summarized that the goals of his policies were to:[90]

1. **Help the Services do a Better Job.** Improvement in the development and acquisition of new weapons systems will be achieved to the extent the Services are willing and able to improve their management practices. The Services have the primary responsibility to get the job done, OSD offices should see that appropriate policies are established and evaluate the performance of the Services in implementing these policies.

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90 David Packard, "Toward Better Management of — The Development and Acquisition of New Weapons Systems," *Defense Management Journal* 7 (Fall 1971): 2-7, (See Appendix D). The article is based on testimony presented in April 1971.

2. **Have Good Program Managers with Authority and Responsibility.** If the Services are to do a better job, they must assign better program managers to these projects. These managers must be given an appropriate staff and the responsibility and the authority to do the job and they must be kept in the job long enough to get something done.
3. **Control Cost by Trade-offs.** The most effective way to control the cost of a development program is to make practical trade-offs between operating requirements and engineering design.
4. **Make the First Decision Right.** The initial decision to go ahead with full-scale development of a particular program is the most important decision of the program. If this decision is wrong, the program is doomed to failure. To make this decision correctly generally will require that the program be kept in advanced development long enough to resolve the key technical uncertainties, and to see that they are matched with key operating requirements before the decision to go ahead is made.
5. **Fly Before You Buy.** Engineering development must be completed before substantial commitment to production is made.
6. **Put More Emphasis on Hardware, Less on Paper Studies.** Logistic support, training and maintenance problems must be considered early in the development, but premature implementation of these matters tends to be wasteful.
7. **Eliminate Total Package Procurement.** It is not possible to determine the production cost of a complex new weapon before it is developed. The total package procurement procedure is unworkable. It should not be used.
8. **Use the Type of Contract Appropriate for the Job.** Development contracts for new major weapon systems should be cost-incentive type contracts. (a) Cost control of a development program can be achieved by better management. (b) A prime objective of every development program must be to minimize the life-cycle cost as well as the production cost of the article or system being developed. (c) Price competition is virtually meaningless in selecting a contractor for a cost-incentive program. Other factors must control the selection.

To meet oversight requirements, the Packard policies established three decision points (later to become “milestones”) that programs would ordinarily pass through: initiation, beginning of full scale development, and beginning of production and deployment. To review programs at these points the Packard policies set up a Defense Systems Acquisition Review Council (DSARC). The plans were to be documented in a “development concept paper” (DCP), not to exceed twenty pages, that would lay out the program issues, including special logistics problems, program objectives, program plans, performance parameters, areas of major risk, system alternatives and acquisition strategy. (The DCP was renamed “decision coordinating paper” with the issuance of the first DOD Directive 5000.1 on 13 July 1971, but without material change in its form or content.) Following the DSARC, DDR&E would coordinate the DCP with the members of the DSARC (who were the OSD assistant secretaries and other top officials directly concerned with acquisition matters) and send it with his recommendation to the DEPSECDEF (who exercised the formal decision authority). Reviews might be conducted at other points as well, but Packard emphasized that program managers were not to be peppered with OSD demands for information.[91]

As is always the case with policy statements, it is difficult if not impossible to disentangle the elements included in order to appeal to various constituencies from those which derive straightforwardly from analysis of experience. In particular, it appears likely that the ban on TPP was the result of its toxic association with the venomously criticized C-5A program rather than the carefully supported and reasoned criticisms of Peck and Scherer.[92]

The extent to which DOD is really a loose federation and is thus not amenable to overall policy direction may or may not have been apparent to Packard, as a high-tech commercial industrialist without much direct experience with government (even as a contractor). Nor is it clear how completely he recognized the strong pressures faced by program managers, as officers dependent on their Service for future assignment and promotion prospects, to conform to the desires of senior officers, even those who had no nominal authority over them. These factors had been examined and noted by management and social scientists studying defense, but we do not know how familiar Packard was with their work or what he thought of it.[93] What is clear is that when taken together with the great variability inherent in weapons developments, they made his

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91 DEPSECDEF memo for secretaries of military departments, et al, of 30 May 1969, “Establishment of a Defense Systems Acquisition Review Council”; DDR&E and ASD(I&L) memo for DEPSECDEF of 19 Jul 1969, “Defense Systems Acquisition Review Council Administrative Procedures”; David Packard, “Policy Guidance on Major Weapon System Acquisition,” *Defense Management Journal* 6 (Summer 1970): 56-59; “Address by the Honorable David Packard, Deputy Secretary of Defense, at Armed Forces Management Association Dinner, International Hotel, Los Angeles, Calif. Thursday, August 20, 1970,” *Defense Management Journal* 6 (Summer 1970): 60-63, (all See Appendix D).

92 Shannon A. Brown and Walton S. Moody, “Defense Acquisition in the 1970s: Retrenchment and Reform,” in *Providing the Means of War: Historical Perspectives on Defense Acquisition, 1945-2000*, ed. Shannon A. Brown (Washington, DC: U.S. Army Center of Military History and Industrial College of the Armed Forces, 2005), 148.

93 Merton J. Peck and Frederic M. Scherer, *The Weapons Acquisition Process: An Economic Analysis* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1962), 67-97, passim.

vision very difficult to implement and vulnerable to “gaming” by those disinclined to live within it.

B. Foster’s Policies for DDR&E

Immediately following Packard’s article in the *Defense Management Journal* was one by John Foster that addressed many of the same concerns but which differed in some respects in tone and focus. In it Foster attributed the problems that had been encountered in acquisition to five “bad judgments”:

> Too many people have believed that careful paper analysis alone would substitute adequately for the demonstration of feasibility through fabrication of hardware or for hardware experience which enables us to get a better handle on cost. We now realize that the kinds of uncertainties typical in paper analyses usually lead to greatly increased costs and considerable time lags—both contributing to today’s difficult defense credibility problem.
>
> The hardware item that was “required” was normally defined by a set of rigid and highly detailed specifications. This was done despite the fact that the specifications as a set were not, in many cases, within the state-of-the-art, or even critical to essential system objectives.
>
> The degree of concurrency attempted between development and production was too great. This overlap between the completion of development efforts and the start of production was driven by two factors. The first was the apparent urgency of the date for initial operational capability (IOC); and, second, the effort to reduce total costs by shortening the time span and thereby reducing overhead. The fact was that the dates were often missed, and in retrospect, there is a serious question whether they were all that critical. The cost targets were not met because, as we should have expected, unforeseen problems arose which required time and money to solve.
>
> Almost everyone seemed to be involved in the management of the program. It was like the alumni running the ball game. Yet, in retrospect, it is hard to prove a net beneficial effect.
>
> This approach was cast into very demanding contracts. Indeed, in some cases the contract was the chief concern; and concern for contract compliance drove the actions in the program in a direction contrary to those that were in the best interests of the Department of Defense. [94]

After his statement of these sins, Foster addressed what he saw as the major technological opportunities and needs. Taking his cue no doubt from Fowler he cited

[94] John S. Foster, Jr., “Defense Systems Acquisition—As Seen by the Director of Defense Research and Engineering,” *Defense Management Journal* 7 (Fall 1971): 8-11, (See Appendix D).

examples of over elaborate, costly, and unreliable electronic systems, calling for a much more disciplined approach. (He did not cite the F-111 digital avionics system, which was one of the worst examples of technology over-ambition and which had been actively promoted by DDR&E earlier.)

Caught between his vision of a rapidly increasing Soviet threat and the demands of affordability, Foster saw a solution in "revolutionary" systems that would not depend on impractical complexity or high cost to provide effectiveness. He gave six examples to illustrate his point:

- **Smart bombs.** They find their own way to the targets while the delivery vehicles scoot to safety. They hit their targets almost every time. One bomb on one sortie does it. With conventional dumb bombs, with wartime CEPs, you have to pour them into a target area by the hundreds. A smart bomb can cost ten times as much as a conventional bomb, but it can be 100 times as effective in destroying a target. It seems likely that we will be able to afford adequate numbers of smart bombs in the future; but we could not afford adequate numbers of conventional bombs and their myriad complex delivery vehicles and attrition rates.
- **Forward looking infrared systems (FLIR).** Long wavelength infrared sensors have already helped significantly in Southeast Asia. Their extension is obvious and can revolutionize our capabilities elsewhere in the future.
- **Ground sensors.** They may turn out to be the most revolutionizing technological advance of the Southeast Asian battlefield.
- **Communications.** All Services are in sight of some truly impressive new techniques.
- **Telecraft.** These "remotely piloted" vehicles show promise of extending the hand and mind of man into combat situations where the man himself could not expect to survive.
- **Air-to-air weapons.** New varieties could make the 10-fold jump in performance which is needed.[95]

Some of Foster's visions proved to have unsuspected flaws, but all in all it was a reasonable list of promising developments. How much difference such initiatives could really make in an overall perspective, and how much difference was really needed, were not addressed.

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[95] Ibid.

What is clear is that DDR&E was a driving force in deciding what was to be acquired and how. One example was provided late in 1973, shortly after Malcolm R. Currie, a prominent engineering physicist with a strong electronics background and high-level industry executive, replaced Foster. Currie had, essentially by chance, met the Colonel managing an Air Force program to develop a satellite system for navigation and been briefed on it during the turnover period mid-year. Although he had only limited information about it, Currie quickly grasped the essentials. When the Air Force came to the DSARC in August to get permission to proceed with full scale development Currie was sharply critical of what he correctly perceived as defects in the Service's proposals, and he directed the Air Force to seek input from others – the Navy particularly – which had important contributions to make. The program manager promptly reordered the program to meet Currie's demands, secured approval from a second DSARC in December, and went on to develop the GPS (Global Positioning System).[96]

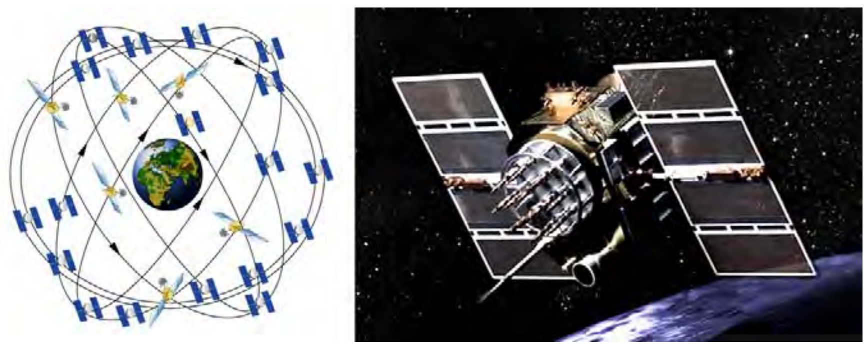

Figure 8. GPS: Constellation (left) and Impression of the Spacecraft (right)

One point to note is that technically Currie, as DDR&E, lacked the authority to direct that Air Force to reorient the program; in principle the SECDEF/DEPSECDEF held the decision authority. The Air Force leadership might have appealed the decision. But perhaps they calculated that this was very unlikely to succeed, and not worth the ill feeling it could generate.

C. Transformation in the Tactical Warfare Directorate

Late in 1970 Fowler left his job as Deputy Director (Tactical Warfare Programs) to return to work in industry. He was succeeded by David R. Heebner, who served until 1975. Heebner, an electronics engineer, had served as a naval officer during World War II and Korea, before going to Hughes Aircraft. Hughes was by then essentially a defense electronics firm rather than an aircraft company (as its name confusingly implied) and

96 This account is based on an oral history interview with Brad Parkinson (who had been the program manager), conducted in 1999 by Michael Geselowitz, IEEE History Center, New Brunswick, NJ, together with contemporary conversations that O'Neil had with Navy participants.

there he had played a key role in the development of towed acoustic arrays for detecting submarines by listening for the sounds they made. He had first joined DDR&E in 1968 and already knew the organization well by the time he moved up to succeed Fowler.[97]

Heebner, who was on very good terms with Foster, was similarly confident of his own judgment and, in guidance to the TWP staff while the principal author was a member, made clear he was not inclined to defer unquestioningly to the views of military officers, even on operational matters. Echoing Foster's clear expectations, he encouraged the staff to go beyond simply reviewing Service proposals and to take an active role in innovation. As positions opened in his organization, he moved to fill them with people he saw as well-qualified and able to exercise independent judgment.

The process continued and even accelerated with the arrival of Currie as DDR&E. Heebner had worked under Currie at Hughes and they had a very good relationship. Heebner and his staff did not hesitate to recommend steps comparable to those Currie had taken on GPS, or to take smaller steps in a similar spirit on their own as the situation seemed to demand. In so doing they acted not on the basis of authority they did not possess, but on the implied threat of higher authority. As was made clear to everyone on the staff, Currie was at least as insistent on DDR&E's responsibilities for innovation as Foster had been.

Heebner's departure in 1975 brought to a close the most active period of DDR&E involvement in setting the course of acquisition programs.

D. Mission Analysis and Engineering

Heebner was a proponent of mission analysis and systems engineering on a mission-wide basis. His predecessor, Fowler, had also been a proponent and practitioner, but Heebner deepened and broadened the thrust.

1. Development of Mission Analysis

Mission analysis in DDR&E had somewhat complex origins that are important to understand because they influenced the organization's course. The weapons developers in OSRD had proceeded largely on the basis of discussions and understandings with the users, rather than any serious analysis. The operations analysis groups in OSRD, on the other hand, engaged in serious mission analysis, particularly the naval Operations Research Group, but this had little influence on development programs in the comparatively brief duration of World War II. It did, however, lay important analytical groundwork.

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97 "Defense Scientist David Heebner Dies," *Washington Post*, 6 Jan 2003, B4.

In the period following the war, the country confronted difficult questions of strategy, and correlated issues about which weapons to develop and procure, most seriously nuclear weapons and their delivery systems. The Services were barred, by an act of deliberate policy, from entirely dominating such decisions when the civilian Atomic Energy Commission (AEC) was given control over nuclear weapons programs. As former directors of a major AEC laboratory, the first three DDR&E's were all used to engaging directly and vigorously in decisions not simply of weapons design but of how weapons were to be employed, and how they related to other military systems. And as physicists they, naturally, sought to understand the issues in analytical, quantitative terms.

There was, however, another broadly related strain of mission analysis that was very influential in DOD in the 1960s and into the 1970s. It came to be known, at least for a time, as "systems analysis," and grew out of the World War II operations analysis efforts of the Air Force.[98] These efforts had been primarily in support of the Air Force's preferred mission of strategic bombing, and had involved a number of civilians, as well as analysts in uniform (such as Robert McNamara, who left the Air Force in 1946 as a lieutenant colonel, still not yet thirty years of age).

Following the war, the Air Force passed the leadership role in top-level strategic mission analysis to the RAND Corporation. Although many RAND researchers were involved, a significant part of the effort came under the Economics Department, headed by Charles J. Hitch. As previously noted, Hitch became DOD Comptroller under McNamara in 1961, and among other things set up the office of Systems Analysis, led by Alain Enthoven. For many years SA and its Program Analysis and Evaluation (PA&E) successor were dominated by economists who largely approached mission analysis in the spirit of Hitch and his RAND followers.[99] That is to say, they considered how changes in the allocation of resources might best improve mission effectiveness – a classic economic concern, now applied to defense.

The approach and focus of the engineers and applied scientists at DDR&E were different. Economy of means has always been a crucial concern for engineers, but they view this not as a separable analytical problem but rather as an analytical input to the central process of design, with the ultimate objective being synthesizing a system design that can improve effectiveness with minimal resource inputs.

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98 Until 1947 the Air Force was nominally subordinate to the Army, but during World War II it was effectively independent.

99 Hitch's approach to mission analysis is clearly and forcefully presented in the book he wrote with Roland N. McKean (and contributions from Enthoven and other RAND colleagues), *The Economics of Defense in the Nuclear Age* (Cambridge, MA: Harvard University Press, 1963), http://www.rand.org/pubs/reports/R346/.

In practice, the two communities had a good deal to learn from one another, but the learning process did not always go smoothly or easily. As we have seen, relations between SA and DDR&E were sometimes strained. By the 1970s, however, the two, for the most part, understood one another better. DDR&E personnel contributed data and insights to support PA&E's analyses of how to improve resource allocations, while PA&E personnel often had a hand in DDR&E efforts to understand and improve mission-wide systems. The interchange was beneficial to both, and to DOD as a whole.

2. Mission Area System Engineering in the 1970s

Mission area approaches were not well developed in the DDR&E of the 1960s, and this contributed to its failings. The F-111 was a major case in point, and understood as such within the DDR&E staff of a later period. Clearly, if DDR&E had acted to understand and highlight the implications of the commonality requirement, the requirements for long supersonic run-in and for high supersonic speed, and the Navy's requirements for a very bulky sensor and weapon suite, as well as the fact that the mission for which the aircraft was being designed diverged sharply from what the SECDEF wanted, the outcome might very well have been significantly better.

By the 1970s the mission area view had been generally accepted as normal and needed. Certainly this was true in TWP, where it had been most absent in the preceding decade.

The effects can be seen, in one way and another, in most of the remaining case studies that will be presented here. Undersea surveillance, covered in the following section, was the subject of one of the relatively few area coordinating papers (ACPs) to be completed. These had begun with an ACP that disentangled the air-launched munitions programs, where the demands of the Vietnam War, concerns about Warsaw Pact threats in Europe, and rapidly-emerging technological possibilities had united to spawn a welter of competing and overlapping programs. The undersea surveillance ACP was among a handful that soon followed. But then the ACP process rapidly fell into desuetude.

There were three reasons. The first was that an ACP consumed a great deal of staff time, and the lean DDR&E of the 1970s could not afford to devote resources to efforts with limited payoff. Second, each ACP tended to be a battleground with the Services, which almost invariably responded negatively. Most importantly, however, it was simply too rigid a structure to meet the need. Any choice of mission areas for ACPs was bound to be inherently and unavoidably arbitrary. But an arbitrary, a priori division of missions could never meet the real need for analyses to form an integral part of mission area systems engineering. Each system synthesis needed to be guided by ideas about where there might be need and opportunity for major improvement. While such ideas might arise in the course of developing ACPs, experience confirmed that it tended to be a relatively unproductive way to go about it.[100]

So DDR&E relatively quickly shifted to a more flexible approach of informal mission area systems engineering efforts. But this approach, unfortunately, left relatively little documentation for the permanent record. In an era before desktop computing, all records had to be kept by hand and typewriter. Anything that required a computer had to be programmed in FORTRAN and submitted as a batch job, usually overnight. But most calculations had to be done with slide rules or hand calculators (for which staff members had spent a large fraction of a week's pay) and recorded by hand, with graphs drawn by hand. Supply cabinets were all well stocked with a variety of graph papers and cross-ruled calculation sheets. Engineers of that time had the necessary skills, but it was not a situation conducive to well-organized and preserved records.

What we have instead are articles and papers about or drawn from mission area systems engineering efforts, together with the recollections of surviving DDR&E veterans. For convenience, in this paper we have relied heavily on articles and papers from the collection of the primary author, William D. O'Neil, but there is nothing unique about them.

The articles and papers were not formal official documents. Rather, they were intended not only to inform, but often to persuade a variety of audiences. They were very rarely academic audiences and so the argument was rarely presented in highly structured and formalized terms. Those that applied specifically to particular cases will be reviewed in the appropriate sections, but we will use a few others to illustrate the general features of mission area systems engineering in DDR&E.

E. Surveillance, Sensors, and Related Issues

Programs to acquire vehicles (aircraft, ships, etc.) were almost always the most expensive and attracted the greatest attention from the top leadership, Congress, and the public. Weapons and weapons systems also were prominent. Surveillance and sensor systems rarely cost as much or commanded as much attention.

Yet the military – and not just in the United States by any means – was prone to buy vehicles for which it had no truly effective armament systems, and weapons that were designed to hit targets that current surveillance systems could not detect and sensor systems could not locate.[101] For these reasons, DDR&E generally devoted more attention

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[100] This reflects O'Neil's discussions at the time with Heebner and Peterson, as well as his observations of how DDR&E offices conducted their business.

[101] William D. O'Neil, *Technology and Naval War* (Washington, DC: Department of Defense, Nov 1981), (See Appendix D).

to surveillance and sensor issues than their level of funding or public attention might seem to imply, and made them a particular focus of innovation.

As noted above, Heebner had made his mark developing the technology for towed arrays of acoustic sensors to detect the noises made by distant submarines. To head the naval warfare office within TWP he brought in Stanley A. Peterson, an engineer from the Navy's Underwater Sound Laboratory (which had originated as the Harvard Underwater Sound Laboratory in World War II under OSRD) and under him Gerald A. Cann, whose academic background was in geology and geophysics and who had worked in industry on antisubmarine sensors.[102] (Cann moved up when Peterson left in 1975, and in 1977 left DDR&E for a senior Navy post. He eventually became the Assistant Secretary of the Navy (Research, Development, and Acquisition), 1990-93.)

With Heebner's encouragement and backing, Peterson and Cann exerted a great deal of influence over the Navy's development of antisubmarine surveillance and sensor systems. Opportunities and challenges were expanding very rapidly due to advances in the understanding of underwater acoustics, developments in electronics technology, and rapidly increasing computational power. The two men had a wide circle of contacts in the relevant technical fields and the personal knowledge to understand and accurately evaluate what they were hearing. Their influence over program and budget decisions provided a powerful incentive for people to want to give them information. And their influence and ability gave them entrée and influence with the leaders of the Navy's antisubmarine warfare community. All these factors contributed to their success and to the rapid development of system capabilities. They did not innovate any new technology ideas while at DDR&E, but they synthesized the technologies that had been developed in a variety of places into successful system architectures.

This story was repeated with variations in a number of other areas, including radars for various purposes, infrared and optical systems, and electronic warfare, all ripe for comparable advances. Unfortunately, it is difficult to describe specific cases in any detail. Virtually all of the material relating to these issues was classified, making it impossible for the people involved to retain it in their personal files. If any of it has survived, we did not find it within the limits of this study. Later in this paper we will, however, discuss one particular surveillance system in detail.

Shortly after Cann was hired in September 1970, he worked on an ACP for undersea surveillance that was published and approved in 1971. This ACP was very influential and

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[102] It was geophysicists who had pioneered the towed array – when combined with a source of low frequency sound such as small explosive charges or percussive air guns the array is used to map the echoes from the geologic layers beneath the sea bottom.

served as a roadmap for undersea surveillance for much of the following decade, and beyond.[103]

Earlier in 1970, while Cann was still working for a support contractor, he wrote a classified summary article that gives a general idea of how the undersea surveillance ACP itself was structured. [104] After a succinct review of the overall strategic and tactical background, together with the principal constraints, it outlines the principal options. This is followed by a section entitled "Surveillance Concepts," describing the mission of undersea surveillance, with basic measures of effectiveness, and assessing the overall balance of effectiveness against the current Soviet threats. The section on "Threat Considerations" addresses not only current threats, but projections of future threats, in terms of the parameters that affected their detectability. A more detailed quantitative exploration of the system challenges comes under "Issues," while the section headed "Areas of Potential Improvement" probes options for development architectures, including limited qualitative assessment of costs and cost impacts. The article is completed by two appendices, one describing "Present Capability," and another going into "Future Systems Planned." While there was no specific form for DDR&E mission systems engineering assessments, this is broadly typical.

The effects of Cann's mission area analyses can be seen in the development of the Surveillance Towed Array Sensor System (SURTASS). Before joining DDR&E, Cann had contributed to analyses demonstrating the need for a mobile system to complement the fixed Sound Surveillance System (SOSUS). The mobile system would tow an acoustic array thousands of feet long at a depth deep enough to detect low-frequency noise made by submarines hundreds of miles away.[105] The Navy responded with a proposal for towing a long array from destroyers or frigates, in other words, fast general purpose warships. But because the arrays were created to listen for very faint sounds, it was essential that they be towed as slowly as possible to minimize environmental noise. This was a poor match for a destroyer or frigate, and tying up a general-purpose warship for the sole function of towing an array seemed to make little sense as well.

Working over a weekend, Cann resolved this issue by producing an analysis showing that smaller ships modeled on those used to service oil drilling platforms at sea could be used to tow the arrays. He calculated that only a small number of ships were required, if they were dedicated to the surveillance task, with a considerable overall

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[103] Based in part on telephone conversations between O'Neil and Cann in July and August 2010.

[104] Gerald A. Cann, "Undersea Surveillance in the 1970's and 1980's (U)," *Journal of Defense Research*, Series B, Vol. 2B, No. 3 (Fall 1970): 191-204. Article classified SECRET. DTIC Accession Number AD0513497.

[105] Edward C. Whitman, "SOSUS: The 'Secret Weapon' of Undersea Surveillance," *Undersea Warfare* 7, No. 2 (Winter 2005).

savings. Minimal, largely civilian crews could be used because the data collected by the array could be relayed automatically to shore stations for processing. Cann's analysis became the basis for the SURTASS.

F. Case 4: Radar Stealth

Few would dispute that radar stealth has been the single most dramatic development in technology for combat aircraft since the advent of jet propulsion, more than thirty years earlier.[106] The desirability of reducing aircraft radar cross section (RCS) was apparent to the earliest radar designers, but the practical problems in achieving reductions sufficient to be tactically significant resisted repeated efforts for decades.[107] By the early 1970s, theoretical advances, improved understanding of materials properties, and computational advances held the promise of better results.

This was fortuitous because the increasing strength of air defenses was raising concerns about the feasibility of conducting air operations over or even near enemy territory. The most potent of the air defenses were radar guided and it seemed that a major reduction in radar visibility of aircraft might restore their freedom of action. This was a tall order because in general it requires a sixteen-fold reduction in RCS to cut radar range in half, or a ten-thousand fold reduction in RCS to cut the range by 90 percent. By the early 1970s techniques had been developed that permitted an approximate ten-fold reduction in RCS. While this could be useful in making electronic countermeasures more effective, it was not of great tactical significance in itself and conferred quite limited

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106 This story of the origins of the stealth program and DDR&E's involvement has been pieced together from a variety of sources. David C. Aronstein and Albert C. Piccirillo, *Have Blue and the F-117A: Evolution of the "Stealth Fighter"* (Reston, VA: American Institute of Aeronautics and Astronautics, 1997) is an excellent study, but for the story of the origins the authors relied on a limited number of working level sources who lacked first-hand knowledge of some key events. Ben R. Rich with Leo Janos, *Skunk Works: A Personal Memoir of My Years at Lockheed* (Boston: Little, Brown & Co., 1994) is important but covers only the Lockheed perspective. For this study O'Neil has exchanged a number of e-mails with C. E. "Chuck" Myers, who played a central role that has often been neglected in existing accounts. In addition, O'Neil knew a number of the key participants and has incorporated what he heard from them, mostly in confirmation of what he found in the Myers correspondence and the published sources.

107 If a target is illuminated by a source of radar energy from a particular direction with a certain incident power density per unit area and re-radiates some fraction of that energy per unit solid angle in a chosen direction (usually but not always chosen to be back at the source and co-located receiver) then the ratio of the re-radiated fraction to the incident power density is the *radar cross section*, RCS (usually represented in equations by σ). Mathematically, RCS has dimensions of area and is usually expressed in square meters or in decibels (dB) relative to a one square meter reference area, but this is really only due to the way that the radar equations are formulated and must not be taken to imply that RCS is related in any direct way to the physical size of the target, for under many circumstances it is not. It does depend on the frequency of the radar energy, the electrical characteristics of the target's surfaces, and the spatial arrangement of the elements of the surfaces relative to the directions of illumination and re-radiation.

protection. Something closer to a ten-thousand fold reduction in RCS was what was needed to have a major impact.

In a daring and very secret technology program codenamed HAVE BLUE, ARPA and the Air Force developed and proved the effectiveness of techniques to cut RCS by enough to have a dramatic tactical effect. The Air Force applied these techniques in the SENIOR TREND program, resulting in the Lockheed F-117A Nighthawk "stealth fighter" which subsequently fought in several conflicts. Further developments brought the stealthy Northrop B-2 Spirit bomber, Lockheed F-22A Raptor fighter, and Lockheed Martin F-35 Lightning II series of joint strike fighter variants, together with a number of stealthy missile programs.

Reflecting its great success, stealth has been claimed by many fathers. In reality, it was a stream fed by many springs and DDR&E played a role in crystallizing the program and securing support.

The story really begins in 1971 when Foster asked an innovative electronics materials scientist named George H. Heilmeier to take over the DDR&E office dealing with electronic and physical sciences. Heilmeier was in no doubt that Foster meant him to take a positive and active role, which definitely came naturally to him. When Currie replaced Foster as DDR&E, he found a kindred spirit in Heilmeier, and when the position of ARPA director came open early in 1975 he asked Heilmeier to take it. Heilmeier and Currie were in agreement that the agency needed to take a stronger lead in innovating technologies that would bring important new military capabilities.[108]

While at DDR&E, the dynamic Heilmeier had developed wide and productive contacts with other parts of the staff. His office was concerned with basic research, applied research, and limited parts of advanced development, but he kept in touch with those in Heebner's directorate and elsewhere who had responsibility for the systems that these technology base efforts existed to feed. When Heilmeier went to ARPA he polled people in DDR&E about the technologies ARPA could work on that were good prospects for having a strong impact if success were achieved.

One suggestion came from another dynamic figure on the DDR&E staff, C. E. "Chuck" Myers, a colorful man with a colorful history. While still in his teens he had flown as an attack bomber pilot in the Pacific for the Army Air Forces (the predecessor of the Air Force) in the final two years of World War II. After the war he got an engineering degree but decided to go back to flying, this time for the Navy, piloting carrier-based jet fighter-bombers in the Korean War. He qualified as a test pilot before leaving the Service

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[108] George H. Heilmeier, OH 226. Oral history interview by Arthur L. Norberg, 27 March 1991, Livingston, New Jersey. Charles Babbage Institute, University of Minnesota, Minneapolis. Owing to the purpose of this oral history collection the interview focuses on artificial intelligence, but that was only a relatively small part of what Heilmeier did at ARPA.

for family reasons and became a noted experimental test pilot for industry. His interest in innovative concepts for air warfare and the vigor and effectiveness with which he pursued them led him to become a kind of free-lance technical marketer, with a prominent place in the “fighter mafia” that did a great deal to bring about major initiatives including the Lightweight Fighter (LWF, progenitor of the F-16 and F/A-18) and the A-X (which led to the A-10).[109]

In 1973, Heebner recruited Myers to head the air warfare office within his TWP organization. Based on the principal author’s firsthand knowledge of the situation, Heebner valued Myers for his effective efforts to push the LWF, which Heebner himself supported strongly. Before coming to DDR&E, Myers had already reached the conclusion that, as he puts it, “the most important characteristic of any combat system (including an infantryman) is its signature.”[110] In tests he had observed that smaller aircraft with smaller visual and radar signatures enjoyed an advantage in simulated combat and he was eager to press this further. His vision was of a fleet of hard to detect and hard to hit small planes that could disrupt enemy defenses and throw the enemy command off balance by jabbing unexpectedly at many points, like a cloud of gnats with hornet stingers. He set out to find people who could make this a reality, calling his loose collection of efforts (mostly unfunded) “Project HARVEY.”[111]

One of those who knew about Project HARVEY was Heilmeier. He understood the logic behind it clearly and made stealth one of his foci of innovation at ARPA. Upon his arrival, he found that there was already an active project under Kent Kresa, head of ARPA’s Tactical Technology Office (TTO), focused on achieving dramatic reductions in RCS. A year earlier Kresa had recruited engineer Ken Perko, who had been working on unmanned air vehicles (UAVs) in the Air Force, to head a tactical aircraft program in TTO. Stealth had been a concern in UAVs for some time, and although progress had been limited, Perko now believed that more might soon be feasible. He solicited “white papers” from five aircraft manufacturers, and then awarded two of them, McDonnell Douglas and Northrop, $100,000 contracts to study the problem more deeply.

One major aerospace firm had not been asked for a white paper: Lockheed. In one sense this was remarkable since Lockheed had worked longer and harder on stealth than any of its competitors, due to its efforts to build high-performance reconnaissance

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[109] Myers has much information about his background available on his Web site at http://www.reocities.com/aerocounsel/. Its somewhat unpolished, high voltage tone is characteristic of its owner.

[110] E-mail exchange between Myers and O’Neil, 1 Aug 2010.

[111] Harvey was a fictional character in a Pulitzer-Prize winning play of the same name by Mary Chase, which had a long Broadway run during and after World War II. (There was also a hit 1950 film, and several television adaptations.) He was a magical creature who took the form of a huge rabbit and was invisible to all but his intimates.

aircraft. But the fact that aircraft like the SR-71 Mach 3+ strategic reconnaissance plane even incorporated stealth features was itself closely guarded. Moreover, the Air Force (from which Perko had come) had for quite some time regarded Lockheed with some suspicion.

In 1974 a Lockheed Skunk Works executive named Rus Daniell, whom Myers had known for some time, tried to convince him of the merits of a strike version of the SR-71. Myers did not respond positively to this idea, but told Daniell of the ARPA project and suggested that Lockheed approach Perko. After Lockheed corporate engineering executive, Willis Hawkins, confirmed Daneill's conversation with Myers, Lockheed briefed Perko and Kresa on their extensive stealth experience and offered to participate without ARPA funding.

The offer was accepted and Lockheed soon began to show exciting results. Northrop's somewhat different approach also appeared promising. Perko believed that there was a good chance of a major advance, but he would need much more money and support to go further.

More money meant that there would have to be support from one of the Services. This was not only a matter of the ARPA budget – it was a basic principle of its operation that as programs got bigger and more mature there had to be Service "buy-in," in order to give a solid basis for transition to actual application. Myers had been trying to get Air Force or Navy support for stealth efforts, and now Heilmeier joined his efforts.

Figure 9. The HAVE BLUE Stealth Test Aircraft

Drawing on his network of high-level contacts, Myers took a characteristically bold step. With the willing cooperation of his superiors he arranged a meeting with the Air

Force chief of staff, General David C. Jones, U.S. Air Force (USAF), Currie, Heilmeier, and Kresa. In addition, Jones brought Lieutenant General Alton D. Slay, USAF, who was responsible for drafting requirements for new systems. According to Myers, Jones listened impassively to the briefing, but at the end when Currie asked his view replied, “I don’t see how we can turn away from this.” Slay, who had previously been skeptical, now joined his superior, and the Air Force agreed to lend its support.

This story seems particularly dramatic because of the very high stakes, but in many ways it is typical of DDR&E in the Currie-Heebner era, when it stood at its peak of innovative energy. Myers had no great knowledge of the technology of RCS reduction, and lacked both the time and motivation to dig deeply. But he understood enough of both the technological and mission aspects to recognize that there was a very real possibility of major impact, and with the encouragement and support of Currie and Heebner he strove with energy and imagination to develop support. On the technology side the impetus was supplied by Heilmeier, a recent DDR&E veteran with his own mandate for innovation from Currie.

None of this would have been effective if Perko and his contractors had been unable to meet the formidable technological challenges. Myers did not know enough to form a sound assessment of their chances. But Heilmeier, with a strong background in the relevant technologies and good technological judgment, was well able to fill that gap and recognize that the work merited support.

In the end, however, stealth technology was never really tried for the mission conceived by Myers, in which large numbers of hard-to-see and hard-to-hit aircraft, not necessarily extremely stealthy, would confuse and saturate air defenses. His concept was, in effect, a precursor to the “swarm” concepts that would later gain much attention in naval warfare. By the time stealth was moving from the technology to the implementation stage Myers had left DDR&E, and his replacement was less well positioned (and perhaps less eager) to pursue this mission concept, especially given the lack of support from Heebner’s successor as the TWP director. Thus the concept died without any serious independent examination. This stands in sharp contrast to other DDR&E-supported mission concepts, and illustrates just how critical DDR&E’s support could be.

G. DDR&E and the Technology Base

While the focus of this paper is primarily on systems acquisition programs, it is important to bear in mind that DDR&E played a key role in shaping and guiding the technology base – and in protecting it from those who did not understand its role or were insufficiently concerned about the longer term. Here, too, it was a major voice in picking the winners and losers, with a potential for major future consequences.

Through much of the 1970s the Deputy Director for Science and Technology (DD(S&T)) was John L. Allen. He was on the same level as Heebner and his division was similarly divided into offices, each dealing with broad areas. George Heilmeier headed one of these offices until his departure to lead ARPA. The next few paragraphs will briefly review one example of the work in S&T.

Bartley P. "Bart" Osborne, Jr., joined the office headed by Gerald Makepeace in the fall of 1974 as Staff Specialist for Aeronautics, after eighteen years as a design engineer in the aircraft industry. He remained in the job for four years (as he had agreed) before leaving to return to industry. Midway through his tenure he was assigned added responsibility for ocean vehicles. His responsibilities ranged from basic research through exploratory development to the early phases of advanced development (largely moderate-scale technology demonstration programs). The technology demonstrators tended to command special attention. Somewhat ironically, in light of Osborne's purely fixed-wing aircraft background, most of the action in technology demonstrators at that point was in rotor craft, where several approaches were being pursued to develop hybrid craft that could reach speeds higher than the 180 knots or so to which the retreating blade stall limits pure helicopters. The success of one of these, the Bell XV-15 tilt rotor demonstrator, led to the development of the Bell-Boeing V-22 Osprey. (The well-known problems of the V-22 appear to reflect deficiencies in the later development and testing of that particular aircraft rather than anything the XV-15 should have revealed.[112])

These programs were generally soundly conceived and well managed and Osborne's role was largely restricted to review and support, but there were other areas in which he exerted a much more active and positive influence. One clear example was his role as co-chair (with a senior National Aeronautics and Space Administration (NASA) technology official) of a NASA-DOD panel charged with coordinating NASA and DOD aeronautics research facilities development. New test facilities were essential to development of higher-performance aircraft and engines, and various NASA and military laboratories had plans for them. But the capabilities of these proposed facilities overlapped in some important ways, and if all were to be built, none would be well utilized. Clearly it was essential to do some pruning, but to the laboratories involved these felt like serious losses. When Osborne arrived in 1974 several major decisions about allocation of facilities and responsibilities had been debated for as much as eight years without resolution. He and his NASA co-chair were resolved to reach a settlement that would serve the needs of the nation.

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[112] [James] Richard Whittle, *The Dream Machine: The Untold History of the Notorious V-22 Osprey* (New York: Simon & Schuster, 2010); Martin D. Maisel, Demo J. Giulianetti, and Daniel C. Dugan, *The History of the XV-15 Tilt Rotor Research Aircraft: From Concept to Flight*, Monographs in Aerospace History #17, NASA SP-2000-4517 (Washington, DC: National Aeronautics and Space Administration, 2000).

The committee took up three major national facilities issues that had been debated seemingly endlessly: the Aeropropulsion Systems Test Facility (ASTF), a specialized wind tunnel for full scale engine test at the Air Force Arnold Engineering Development Center (AEDC) Tullahoma, TN; an added 80’x120’ test section for the 40’x80’ low speed wind tunnel at NASA Ames Research Center; and a high Reynolds number wind tunnel proposed by NASA Langley Research Center, with the site at issue.[113] Issues of cost, cost effectiveness, and need were settled rather promptly for the first two facilities. Design parameters for the third facility were determined after more internal debate but unanimity on facility site could not be achieved, with USAF representatives arguing for Tullahoma as the preferred site.

After an exhaustive review of data and additional argument the majority of the panel agreed that it would best be located at Langley. The Air Force refused to agree, however. Ultimately, on Osborne’s recommendation Currie directed that the facility go to the NASA center. In retrospect it seemed clear that this was the prudent choice, as AEDC became so busy with building and operating other advanced facilities that it was doubtful that it could have adequately supported the high Reynolds number tunnel.

By breaking the deadlock DDR&E made it possible for DOD and NASA to approach Congress in the next budget cycle with a unified national aeronautical facilities update program, giving it the confidence to authorize design and construction of the three major additions. Most importantly, the ASTF was completed and checked out in time to play a significant role in the smooth development of the engines for the Lockheed F-22 fighter. In a sense, this was another example of mission analysis and systems engineering, applied not to warfighting systems but to critical S&T infrastructure.

Again, DDR&E’s influence extended across many areas of technology. Much of this had widespread implications for civil as well as military applications – much as the aeronautical research facilities did. For instance, DDR&E led a series of technology development programs in areas such as gas turbine component technology, aerospace materials, electron devices, and integrated circuit manufacturing. It faced frequent criticism that such programs should be left to the market, with industry funding the programs it benefitted from. This issue was repeatedly addressed in each area and it lead to changes as circumstances evolved, but in many cases the idea of leaving technology development in industry hands was not realistic. The examples often cited in support of the notion, such as the AT&T Bell Laboratories development of the transistor, were not

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[113] The *Reynolds number*, a fundamental parameter in fluid dynamics, is the dimensionless ratio of inertial to viscous forces in a fluid flow case. For the most accurate prediction, models must be tested at Reynolds number equivalent to that of the full-scale vehicle, which is not possible in ordinary wind tunnels.

meaningful in most of the cases of importance to DOD. Indeed, when carefully considered, they tended to prove DDR&E's point.

A fundamental issue industry faces in development of technology is appropriability of the benefits. Even if an investment promises great value, it may not be commercially attractive to pursue if the firm cannot be reasonably certain of its ability to appropriate enough of the economic benefits it will bring. If the firm occupies a monopoly or quasi-monopoly position in its industry (as AT&T did in telecommunications at the time of the transistor's development) then it may feel confident of appropriating adequate benefits to justify the risk and expense of technology development. But such positions were rare in the defense industry at that time, in part because government policy actively discouraged them. In addition, profit policies in government contracting further limited the firm's ability to appropriate the benefits over the long term. The government, on the other hand, was in a much stronger position to capture the full benefits of technology development and thus it was a relatively better investment for the government than for contractors.

5. The Case of the 2000–3000 Ton Surface Effect Ship (SES) Prototype Program

The fullest and most detailed case study of this paper concerns the 2000 ton Surface Effect Ship (SES) program (which grew to a 3000 ton program). While this is far from the largest or most significant program DDR&E dealt with during this period, circumstances make it particularly suitable for a detailed study in that the principal author was intimately involved with it from beginning to end and retained more than 100 copies of program documents in his own personal files.[114] Moreover, the nature of the program provides good opportunities for observing the process DDR&E used to deal with "what to buy" issues.

A. Prototyping

The 2000 ton SES was cast as a prototype program, intended to lead to operational SESs of generally similar characteristics. The use of prototypes for such purposes was by no means new, but Packard is widely credited with helping greatly to revive and reinvigorate the practice.[115] While the principles of prototyping were addressed in various places, there was no single coherent statement of the approval process during his tenure. A few months after he left DOD, however, a memorandum directive was issued.[116] It may be that this was set in motion before his departure, but took a long time to coordinate with the Services; it seems unlikely that he had any objections.

The directive called for a simple and streamlined management process, representing minimal OSD involvement. If the total expenditure was projected to exceed $25 million, however, the DDR&E and relevant Service R&D assistant secretary would jointly approve it in principle, signing a Program Memorandum, before formally soliciting proposals from industry.[117] When the proposals had been evaluated and a source selected the program would be reviewed and the DDR&E would distribute the Program

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[114] These have all been digitized and are published (in electronic form only) in the separate documentation appendix (Appendix D).

[115] David Packard, "Improving R&D Management Through Prototyping," *Defense Management Journal* 8 (Jul 1972): 3-6, (See Appendix D).

[116] SECDEF memo of 2 May 1972, "Prototype Program Approval," (See Appendix D).

[117] For the purposes of defense R&D, $25 million in 1970 is the rough equivalent of $150 million in 2010.

Memorandum for coordination with other offices as he believed necessary, to include Program Analysis and Evaluation (PA&E) for operational practicality prototypes (as opposed to purely technological prototypes). The DEPSECDEF would act as the decision authority for operational practicality prototypes.

B. Surface Effect Ships

Throughout the 1970s, the U.S. Navy pursued a program to develop and build very fast oceangoing ships for escort missions, called surface effect ships. Ultimately, the prototype program was cancelled late in 1979, after the expenditure of more than $300 million dollars — quite a large prototype program by the standards of that time (and the equivalent of well in excess of one billion dollars in 2010). While it was followed by other SES programs on a smaller scale, in DOD and elsewhere, it remains the largest program of its type ever attempted. Today SESs are restricted to a small number of craft in specialized niche roles, and there seems little prospect that the SES will ever be a major type of marine vehicle.

While the SES program ultimately was not successful, it does illustrate many of the ways that Director of Defense Research and Engineering/Under Secretary of Defense for Research and Engineering (DDR&E/USDRE) operated during the period, and the organization's participation in the effort was in itself successful in important respects.

In broad outline an SES resembles a catamaran vessel, with two widely-separated side hulls spanned across their tops by a box-like cross structure housing much of the vessel's systems and payload. It differs from a conventional catamaran in that powerful fans generate a low-pressure cushion of air under the cross structure that carries a large portion of the SES's weight. This air cushion lifts the side hulls so that they just skim the water's surface, thus greatly reducing their drag. In order to contain this cushion, the space between the side hulls is closed at the bow and stern by flexible seals that adjust continuously to ride just at the water's surface.[118]

Since the SES is not a widely familiar technology, Figure 10, shows the principal design features of the U.S. Navy 3000 ton Surface Effect Ship as it was envisioned shortly before the program was cancelled.[119] Schematic cutaways show the most critical systems.

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[118] The technology of surface effect ships is surveyed and their history is outlined in Edward A. Butler, editor, "The Surface Effect Ship," in *Modern Ships and Craft*, published as *Naval Engineers Journal* 97, No. 2, (Feb 1985), ed. William M. Ellsworth, 200-58. M. Rosenblatt & Son Inc., *The Surface Effect Ship: Advanced Design and Technology* (Washington, DC: Surface Effect Ship Project (PM-17), n.d., c. Apr 1975) has more detail about some of the technologies envisioned for the 2000 ton SES program.

[119] Based on Navy program office documents dated 1977 and 1978.

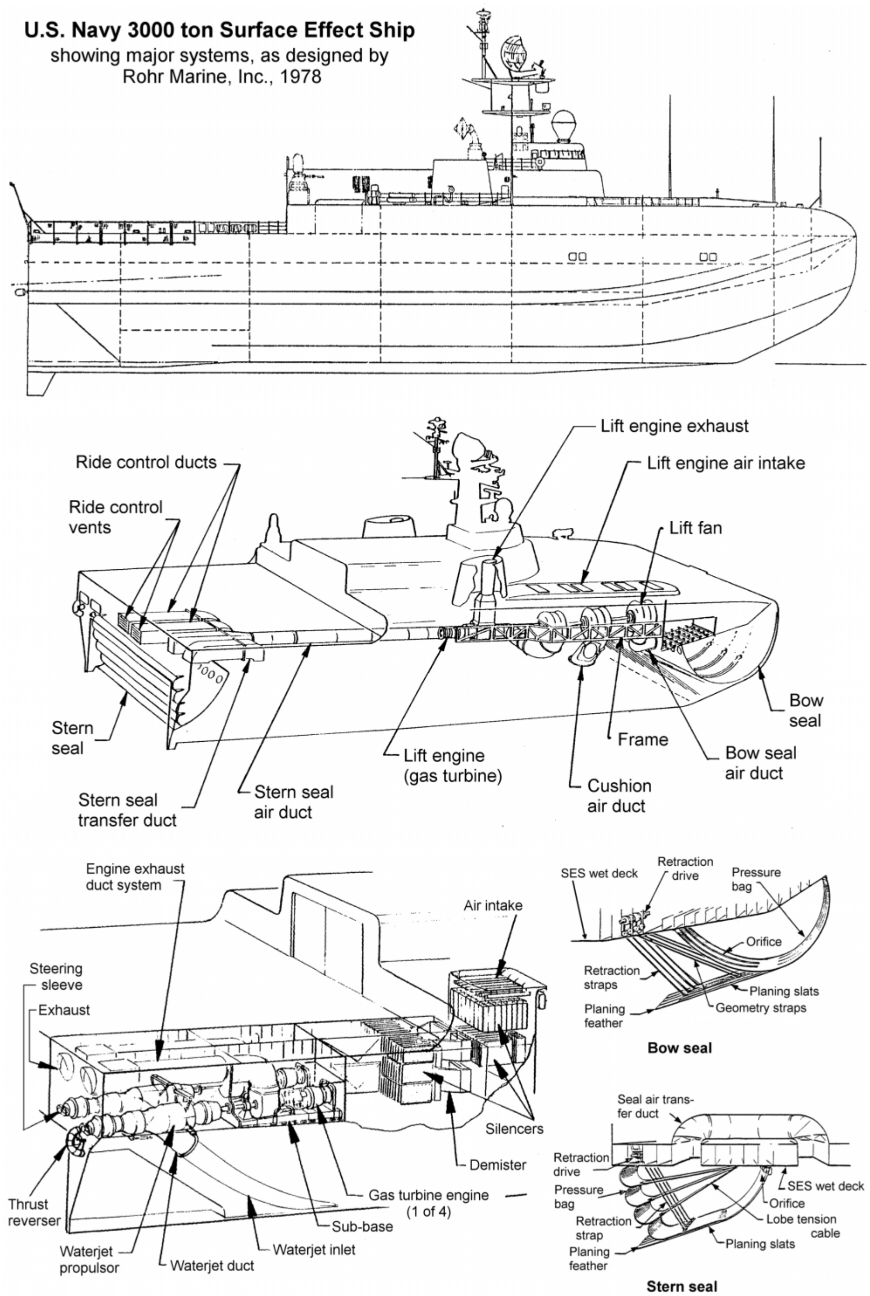

Figure 10. U.S. Navy 3000 ton Surface Effect Ship Concept

There are also closely related craft, usually called air cushion vehicles (ACVs, also known as *hovercraft*, particularly in Britain) that have no immersed hulls and rely on flexible seals all round, supporting their weight entirely by air cushions. The ACV was developed in Britain while the SES was developed in the United States. It differed from the ACV in an effort to solve some of the problems involved in making large, oceangoing vessels. The U.S. Navy's Landing Craft, Air Cushion (LCAC) amphibious lighters are examples of ACVs and display one of their advantages, the ability to ride up on land.[120]

Because the friction of the air cushion is so much lower than that of solid hulls, it is possible to reduce the total drag (or *resistance*, as it is usually called by naval architects) of an SES at high speed to significantly less than that of a conventional ship. But the outcome is not quite as clear-cut as it might seem, due to the interaction of the pressure of the cushion with the water surface, and the power consumed by the generation of the cushion itself.

At very low speeds, the drag of ships generally is dominated by viscous surface friction. As speed increases, a turbulent boundary layer develops and its formation absorbs energy which is often referred to as *form drag.* Both kinds of drag decline with Reynolds number (previously defined) and grow at a rate approximately equal to the square of the speed. However, the motion of the ship through the water creates pressure variations along its length, principally through the Bernoulli effect, and because there is a free surface between the water and the air this gives rise to gravity waves.[121] The energy dissipated through this wave system must be supplied by the ship and is referred to as *wave-making resistance,* or simply as *wave drag.* Because wave propagation is governed by gravity and inertia, wave drag is a function of the ratio of inertial to gravitational forces, measured as ship speed over the square root of the product of the gravitational acceleration and characteristic length (usually the hull length), $v/\sqrt{gl}$, the *Froude number.* [122]

For conventional ships such as destroyers, as the speed expressed in knots significantly exceeds the square root of its waterline length, then wave drag increasingly comes to dominate over friction and form drag, and total drag increases very rapidly,

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[120] The technology and history of ACVs in general, including SESs and other variants, is addressed comprehensively by Peter J. Mantle, *Air Cushion Craft Development* (University Press of the Pacific, 2000). (This appears to be a largely unaltered reprint of *Idem* (First Revision), Report DTNSRD-80/012 (4727 Revised) (Bethesda, MD: D.W. Taylor Naval Ship R&D Center, Jan 1980).)

[121] In fluid dynamics, the *Bernoulli effect* refers to the reciprocal relationship between speed and pressure, with pressure falling as speed increases. Thus as the passage of a hull or air cushion causes water to change speed it results in pressure changes, and since the water is unconstrained at the surface a pressure increases causes the water to rise, while a decrease causes it to fall. These humps and depressions form waves that act under the influence of gravitational and inertial forces, much as the passage of the wind over the surface forms ordinary gravity waves.

[122] It is assumed that the quantities are expressed in consistent units so that the Froude number will be nondimensional. The Froude number is dealt with in most basic texts on naval architecture. For a clear, succinct, and precise development see Philip Mandel, *Water, Air and Interface Vehicles* (Cambridge, MA: MIT Press, 1969).

more rapidly than the square of the speed.[123] At extremely high speeds, however, the wave drag does not increase as rapidly so friction and form drag once again dominate.

Although speeds exceeding 40 knots had been reached by some especially powerful destroyers and cruisers as early as the 1920s, very high drag relative to weight and the resulting very heavy fuel consumption severely limited high speed operation. The normal operating speeds of destroyers and frigates have grown over the years as size has increased and the efficiency of power plants has improved, but in the 1960s it was not feasible for such vessels to cruise for extended periods at speeds much greater than 20 knots. It was hoped that the SES might open a route to much higher operating speeds.

Superficially it might seem as if the SES, with its hulls practically skimming the surface, could evade the constraints of wave drag almost entirely. But the pressure in the air cushion must depress the water surface and thus it creates a wave pattern as the craft moves, just as a solid hull would. So the SES designer needs to consider wave drag, just as any other designer of a high speed ship.

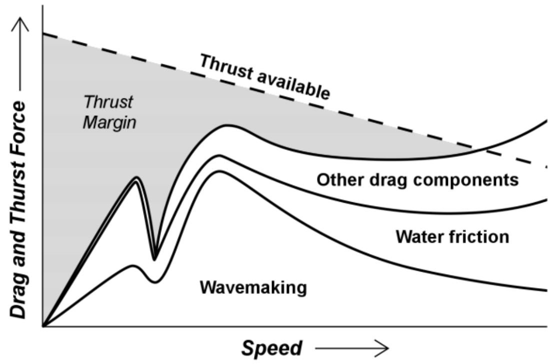

Figure 11. Drag Buildup and Thrust for Large Low-L/B SES

Figure 11 shows the drag buildup and thrust for a typical large SES having a low ratio of length to beam (low L/B), like the 2000-3000 ton SES designs.[124] (Subsequent SES designs have generally had much greater L/B, giving them distinctly different characteristics.) The three categories of drag add, one on top of another, so that the top solid line represents total drag for the SES. For any speed, the net height of the shaded area between this line and the thrust available represents the margin of thrust over drag, which acts to accelerate the SES. There are two humps in the drag curve, a smaller

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[123] The ratio of speed in knots to the square root of waterline length in feet is usually termed the "speed-length" ratio. It is simply a dimensional version of the Froude number, more convenient for quick calculation.

[124] Plot by author O'Neil based on his calculations, drawing from data in a variety of sources. Any such plot is inherently uncertain, given that there never has been an opportunity to collect actual data from a large SES.

secondary hump and then a larger primary hump, with corresponding pinches in the thrust margin. The point at which the thrust line intersects the drag curve marks the highest speed the SES can reach. The drag is affected both by the weight of the SES and the height of the waves; as weight or sea state increase the curve is displaced upward, and also changes its shape somewhat.

C. Origins of the 2000–3000 Ton SES Program

Drawing extensively on earlier British work, the U.S. Navy's R&D community explored the technology and design issues of SESs and ACVs by testing models and several manned prototypes throughout the 1960s. DDR&E and its predecessor organizations do not appear to have played a significant role in shaping or guiding this basic research effort. By the end of the decade, it appears that enough technical information had been amassed to provide a basis for designing larger SESs and predicting their performance. While many of those who were involved in SES research believed that additional development was needed, a few vigorously promoted near-term application of the technology.

The Maritime Administration (MarAd) of the Commerce Department sponsored studies in the early 1960s to explore the hope that SESs might help reverse the decline in the American merchant marine by providing a premium express container service that could fill a gap between air cargo and conventional merchant ships. In the latter part of 1965, the Secretary of Commerce commissioned a blue-ribbon panel of distinguished experts to evaluate the potential. Their report concluded that further research was necessary and drew considerable attention from industry and DOD.[125]

Shortly after the report was issued, MarAd and the Navy joined to form a Joint Surface Effect Ship Program, with plans to build a series of progressively larger prototypes to test the feasibility and develop the technology for large oceangoing mercantile and naval SESs. There were to be 100 ton, 500 ton, and 4000 ton prototypes, with the 4000 ton size seen as the minimum that was potentially viable for ocean commerce.

Within the Navy, attention to the SES was suddenly elevated to the very highest level when Admiral Elmo R. Zumwalt, Jr., became the Chief of Naval Operations (CNO) on 1 July 1970. Zumwalt was a visionary and a reformer who hoped to decisively change the direction of the Navy in a variety of ways. One principal initiative was a "100 knot," oceangoing, SES surface combatant. It was an initiative to which he was personally especially devoted, perhaps in part because he had been a surface officer and high speed

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125 *Surface Effect Ships for Ocean Commerce (SESOC)* (Washington, DC: Department of Commerce, Feb 1966), (See Appendix D).

was seen by some members of the surface community as a means to regain some of the initiative that they had lost to the navy air and submarine communities. Officers and officials in the Department of the Navy were set to work on developing this vision into a fast-paced program.

Early in 1969 the Navy had already contracted with Aerojet-General and Bell Aerospace (which were then major defense contractors operating in many fields of technology) to design and build two high-speed SES test craft of approximately 100 tons gross weight, which came to be known as SES 100A and SES 100B, respectively. It was hoped to have enough test data to support a decision to proceed with the 500 ton craft by mid-1970, but this goal had to be delayed a year when Congress failed to meet the full funding request, and then by more than another two years when the test craft proved more troublesome than had been anticipated.

But a 500 ton craft would not meet Zumwalt's demands for a near-term oceangoing capability. For that, a much bolder leap would be needed. The Navy decided that a 2000 ton SES would be required, with a 10,000 tonner as the longer-term goal.

In the meantime, MarAd withdrew from the program, leaving it entirely in the Navy's hands in 1971.[126]

D. The 2000 Ton SES and the Acquisition Process

1. Defense Systems Acquisition Review Council I (DSARC I)

On 7 July 1972 Zumwalt sent an advance copy of a "streamlined" DCP to Foster with a note urging the earliest possible action.[127] When Assistant Secretary of the Navy (Research and Development) (ASN(R&D)) Robert A. Frosch responded with a 25 July 1972 formal submission, in which he referred to having sent a "Phased Program Plan" to DEPSECDEF on 19 May "in accordance with the earlier understanding reached with DDR&E and Mr. Packard (formerly DEPSECDEF) that this program was to proceed with minimal documentation and in the absence of formal DSARC procedures." He went on to cite a 29 June 1972 memo from DEPSECDEF requiring "formal procedures" and calling for a DCP.[128] His memo contained an "abbreviated" DCP draft of thirteen pages.

[126] The early history is sketched in GAO, "Staff Study, Surface Effect Ships," 093812, Feb 1973, (See Appendix D).

[127] Note from Zumwalt to Foster of 7 Jul 1972, (See Appendix D).

[128] The authors are not in possession of the 29 June memo and are not certain of its relationship to the 2 May memo discussed earlier.

Frosch also referred to Navy approaches to the relevant Congressional committees to secure approval.[129]

At this point the staff specialist responsible for the program in DDR&E was a naval officer with no particular engineering or acquisition background. This officer left no documentary record and we can only speculate about the factors that led Foster to depart from the policy he had recently formulated and require more formal procedures for the SES prototype program. It may very well have been the exceptionally large funding commitment required for a large-scale SES prototype. In any event, his successors would have ample reason to be glad he did.

Compared with the original Navy draft, the final DCP coordination draft was rearranged and somewhat tightened. The most significant change was the addition at its end of sections presenting two program alternatives and an evaluation. In alternative 1, the Navy would proceed at once to preliminary design of the larger ship in parallel with the testing of the 100 ton test craft. Alternative 2 would defer preliminary design until completion of the 100 ton test program. The Navy assessment asserted that alternative 1 would not only speed achievement of a critical capability but would cost less in the end – promulgating the familiar argument that concurrency could reduce costs.

On 3 August Heebner distributed the DCP to the staffs of other DSARC principals for review. The staff of PA&E (then still SA) was not impressed, objecting to the single-minded commitment to a risky and expensive program without fuller consideration of needs and alternatives.[130] The naval officer serving as the DDR&E action officer protested the delay vigorously to his superiors, Peterson and Heebner. It was at that point, Heebner later told study author William O'Neil that he decided he needed someone who could be both knowledgeable and objective to deal with the SES and other major Navy initiatives. With considerable input from Peterson and Heebner, the DCP was revised in an effort to address the various objections, at least in part.

The DSARC met for a Milestone I review on 19 October 1972. The ASN(R&D), Joint Chiefs of Staff representative, the Assistant Secretary of Defense (Systems Analysis), and Deputy Director (Testing and Evaluation) all coordinated by 19 October, but the Assistant Secretary of Defense (Installations and Logistics (ASD(I&L)) did not sign until December. (The Assistant Secretary of Defense (Comptroller) did not date his signature.) The probable reason for the delay was uncertainty about final Congressional action on the FY1973 budget. DEPSECDEF Kenneth Rush issued a memo (an acquisition decision memo, although it was then known as a Secretary of Defense

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[129] Memorandum ASN(R&D) for DDR&E of 25 Jul 1972, "Surface Effect Ship Program," (See Appendix D).

[130] Memorandum Deputy Asst. Secretary (SA) for General Purpose Programs for DD(TWP) of 1 Sep 1972, "Surface Effect Ships (SES) 'For Comment' Draft DCP, Comments on," (See Appendix D).

Decision Memo, or SDDM) on 2 November with the subject of “Surface Effect Ship (SES) Program,” and approved the DCP after Christmas. Without apparent objection from any of the DSARC principals, he approved alternative 1, immediate start of preliminary design.

As revised, the DCP laid out a series of what were in effect critical performance parameters and required prompt notification of any breaches. The preliminary design effort was to cost no more than $10.6 million and be conducted under cost plus fixed fee contracts. Notable Top-Level Requirements (TLRs) specified included a gross weight of 2000 tons, a payload (crew and combat suite) of 250 tons, and a cruising range of 4000 nautical miles at 80 knots in sea state 3. The ship was to have an installed power of 124,000 horsepower (HP), four 25,000 HP gas turbines for propulsion (GE LM2500s, then coming into standard use in the Navy) and two 12,000 HP units to power the lift fans.[131]

In accordance with Rush’s SDDM, the Navy awarded design study contracts for 2000 ton designs to Aerojet-General, Bell Aerospace, Rohr Industries, and Lockheed Missiles and Space in Nov 1972.

The naval officer who had been serving as DDR&E’s staff specialist for the SES program left for another assignment early in 1973. He was replaced on a temporary basis by another naval officer, who was also slated to leave soon. Then the office set out to find a civilian engineer to take over responsibility for this and other programs dealing with what were now being called “naval vehicles.” The choice fell on the principal author of this study, William O’Neil, who was immediately available, had relevant experience, and had favorably impressed DDR&E management, particularly Heebner who interviewed him at length.[132] O’Neil was left in no doubt that he was expected to take a firm and active hand in the SES as well as a number of other programs under his care.[133]

Any questions about whether the program was encountering difficulties had already been erased in April when the Navy program office issued a letter to the contractors observing that the interim review of their work, less than five months into the effort, had shown that all had been finding it impossible to meet the TLRs within anything like the specified 2000 ton size. The letter cautioned them that the size limit had priority and authorized them to propose tradeoffs in the combat suite, if necessary, to meet it. “Innovative design in all areas is strongly encouraged within the bounds of reasonable

[131] “Development Concept Paper, Navy Surface Effect Ship Program,” dated 13 Dec 1972, approved 28(?) Dec 1972, (See Appendix D).

[132] Heebner was then the DD(TWP), two echelons above O’Neil.

[133] In addition to all naval ship programs, his responsibilities included acquisition programs for all non-carrier based naval aircraft, all mine programs, and all mine countermeasures.

technical risk and cost," they were told.[134] The letter was not provided to DDR&E, but it was obtained through contacts within the Navy.

To O'Neil, with his industry background, the letter seemed to sound a note of desperation and over-eagerness to hold to an arbitrary and unrealistic weight limit. He knew that such edicts rarely had good results – it was better to define what the system was to do and tell the designers to find the most economical solution. Putting unrealistic pressure on the contractors could lead them to respond with excessive optimism in an effort to satisfy conflicting demands, while not losing ground to competitors.

In the meantime, the two 100 ton test craft had undergone their initial tests, which revealed a number of problems. Many of these were equipment- or subsystem-related and did not necessarily indicate any overall systemic problems, but some appeared to be fundamental. Of course, this was exactly what they had been built to reveal, but the extent of the problems raised questions about fully resolving them in time to support the fast-paced design and construction effort planned for the much larger ship.

Although already broadly familiar with the SES from his previous work, O'Neil concluded that it was essential for him to understand the technical issues more deeply. He had several other troubled programs to work on as well, but as time allowed he conferred with technical personnel from the contractors and the relevant Navy R&D establishments as well as studying what technical literature he could find. That fall he traveled to Britain, where the ACV had originated and where there were a number of ACVs of various types and configurations in regular commercial as well as military service. Particularly interesting were the 165 ton SR.N4 ACVs, then the largest craft of their type, which had recently initiated regular cross-Channel ferry service at speeds of 50 knots.[135] He was able to make a crossing aboard one of these and to ride on several other ACVs, as well as conferring with British engineers with ACV experience.

His investigations raised a host of issues, particularly about the critical seals that held the air cushion and the ride quality in waves. Moreover, the difficulties the four contractors were having in meeting the TLR led him to question the relationship between weight and performance, which he addressed through analyses based on the methods used in aircraft design, thus greatly clarifying his picture of the performance issue.

The PA&E staff had its own concerns about mission issues. The Navy proposed a variety of missions that could benefit from the high speed of the SES, but focused principally on antisubmarine escort and screening. No existing or envisioned

[134] Contracting officer's letter dated 5 Apr 1973, (See Appendix D).

[135] Successive versions of increased size and capacity carried on this service until 2000, never turning any regular profit, when the new Channel Tunnel with its heavily subsidized rates had made the ACV service even more uneconomic.

antisubmarine sensor could function at speeds in excess of those reached by conventional escorts, so the Navy proposed to employ “sprint-and-drift” tactics. PA&E was far from satisfied with the analyses the Navy offered in support of these ideas. O’Neil kept in close contact with PA&E and his own analyses agreed with theirs rather than with those of the Navy.

2. DSARC IIA

As had been planned at the October 1972 DSARC I, the Navy presented a substantially revised DCP at the end of Oct 1973, to request a Milestone IIA DSARC for approval to proceed with detailed design of the 2000 ton prototype.[136] After further OSD discussions and information exchanges with the Navy, the DSARC proposed various modifications to the DCP.[137]

Over the months preceding the planned DSARC, O’Neil, as the primary action officer, had been consulting with others in DDR&E and with staff members in PA&E, Comptroller, and other OSD offices, in addition to coordinating closely with the Navy. This was the normal practice in DDR&E and both Peterson, then his direct superior, and Heebner had stressed it in their direction to him. Out of these exchanges and his own extensive research, he wrote an extended seventeen page paper for the DDR&E, setting out the issues and alternatives that would be before the DSARC.[138] This was longer than most such papers, reflecting the complexity of the issues, but similar in overall approach and tone. As such it merits attention as an indication of how and how well the staff process worked.

The tone of the paper was professionally sober and dispassionate, but its message was anything but reassuring. It argued that there was virtually no reason to believe that the SES could have anything like the revolutionary effect on naval warfare that Zumwalt and others ascribed to it. It claimed that achieving any effect at all was going to take many years and a great deal of money. And it indicated that there were a series of major risks, most of which were greatly exacerbated by the attempt to build at a scale twenty times as great (in weight) as the 100 ton test craft. So great were the risks, indeed, that one of the four preliminary design contractors, Aerojet-General, declined to submit a price proposal for the detailed design at all due to what it saw as excessive risks – an assessment carrying all the more weight since Aerojet had built and tested one of the two 100 ton prototype craft. Finally, the chairman of the R&D subcommittee of the Senate

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[136] “Decision Coordination Paper, Navy Surface Effect Ship Project,” DCP #109 (Rev), 2 Nov 1973, (See Appendix D).

[137] Memorandum ASN(R&D) for DDR&E of 30 Nov 1973, “ ‘For Comment’ Draft of DCP No. 109, Surface Effect Ship,” (See Appendix D).

[138] “Summary of SES Issues for DDR&E,” 30 Nov 1973, (See Appendix D).

Armed Services Committee wrote to the SECDEF that the committee had strong reservations about proceeding into detailed design due to unresolved risks.[139]

This might have seemed sufficient to sink the program. But the internal politics associated with the SES proved otherwise. The administration that had appointed Admiral Zumwalt as a reformer was still in office and supported him. It was clear that neither Currie nor most of his colleagues at the top levels of OSD wanted to challenge Zumwalt directly on the issue. Currie asked O'Neil to suggest ways the program could be scaled back to reduce funding commitments and risk.[140] After further consultation with Currie, O'Neil elaborated options for risk reduction.

When the CNO attended the DSARC meeting late in December – not at all a common event – the questioning was fairly muted in tone.[141] As was the usual practice, O'Neil took notes, but did not contribute to the deliberations.[142] After consulting with Currie and the office of DEPSECDEF William P. Clements, Jr. (Rush's successor), O'Neil drafted an SDDM for Clements' signature, reflecting the ideas that had been developed for risk reduction and attempting as far as possible to pin the Navy down about specific risk reduction strategies.[143]

3. Down-selection to Two Contractors and Reorientation

Reports reached O'Neil from contacts within the Navy that Zumwalt had expressed distress over the result and that he specifically named O'Neil, whom he identified as an "enemy" of the program, and the force behind the supposed setback. A few days after the decision memorandum had been issued Zumwalt wrote to Clements complaining vigorously about the DSARC process, with the SES as his major case in point. Zumwalt contended that the positions developed by the Navy under his direction regarding issues of needs and technology should not be subject to questioning by the OSD staff. He also complained of leaks, which he attributed to the OSD staff.[144] The Secretary of the Navy (SECNAV) did not forward the memo to Clements. According to information conveyed to the principal author by his contacts within the Navy Secretariat, the Secretary was

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139 Letter Sen. Thomas J. McIntyre to SECDEF of 28 Nov 1973, (See Appendix D).

140 Memorandum O'Neil for DDR&E of 28 Nov 1973, "SES Programs at FY 75 Levels of $40M and $58M," (See Appendix D).

141 "Briefing on Navy's Surface Effect Ship Program to the Defense Systems Acquisition Review Council," by RADM George G. Halvorson and CAPT Carl J. Boyd, 20 Dec 1973, (See Appendix D).

142 Staff members did sometimes pass notes to the DDR&E to respond to specific points that had come up. On some occasions the DDR&E would ask a staff member to speak on some issue.

143 Memorandum DEPSECDEF for SECNAV, "2000-Ton Surface Effect Ship (SES) Prototype Program," 23 Jan 1974, (See Appendix D).

144 Memorandum CNO for DEPSECDEF, "DSARC Proceedings," 13 Feb 1974, (See Appendix D).

persuaded that a broad attack on the entire OSD review process was unlikely to accomplish anything positive, and any investigation of the leaks, which were of questionable importance, was sure to embarrass the Navy at least as much as OSD.

O'Neil found all this somewhat distressing, but others with more experience assured him that it was not too unusual and that it was unlikely to have any real effect.

The Navy worked at top speed to reorient the program to meet the risk reduction demands. A plan was presented to DDR&E in April that added risk reduction efforts while continuing to call for an expensive and fast-paced prototype program involving two ships of different design.[145] The commitment to building the two ships was not acceptable to Currie and Clements, for reasons of both cost and risk, but they agreed to allow the design efforts to proceed in order to avoid a break in contractor effort. On that basis, the Navy issued a revised request for proposals (RFP).

While Aerojet had proposed a program that was arguably closer to the DEPSECDEF direction than the original plan, its proposal was ruled non-responsive and eliminated from the competition. Lockheed's proposal was rated lowest of the remaining three and it, too, was eliminated. The Navy negotiated detailed design contracts with Bell and Rohr, and after resolving funding and authorization issues with Congress, it awarded those contracts at the end of June, just as Zumwalt was relieved as CNO by Admiral James L. Holloway, III, an aviator and nuclear propulsion advocate.[146] Holloway had less passion about the SES than his predecessor, but continued to support it. Zumwalt continued to lobby for it, but, of course, he had much less influence as a retired officer.

In parting, Zumwalt had signed another memo, this time addressed to the SECDEF, complaining about planning procedures generally (without specific mention of the SES, and without problematic indictments).[147] The SECNAV, again, did not forward this second memo. Although they had no effect, these two memos are significant as clear expressions of an underlying tension between Service autonomy and the functions of review and criticism that runs from the very origins of OSD to the present day.

Through further negotiations, Currie and the Secretary of the Navy reached an "understanding" concerning the funding and direction of the program. The agreement included a full DSARC review prior to proceeding with contract design and construction

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[145] Memorandum ASN(R&D) for DDR&E, "Revised DCP #109, Surface Effect Ships," 9 Apr 1974, (See Appendix D).

[146] "Contract Awards," *New York Times*, 3 Jul 1974, 48; Letter CHNAVSEA to CNO, "DCP Update," 19 Sep 1974, (See Appendix D).

[147] Memorandum CNO for SECDEF, "Weapons System Planning Procedures," 21 Jun 1974, (See Appendix D).

of a single prototype. The DSARC was to review not only the preliminary designs but also the results of the risk reduction programs.[148]

4. Alternative Designs

As mention earlier, the 2000/3000 ton SES had a ratio of length to beam (L/B) of about two, meaning it was about half as wide as it was long. It is possible to design SESs with other values of L/B, resulting in different characteristics, and while the large SES program was in progress, low-level work on other kinds of SES continued at various places, including the Naval Ship R&D Center (NSRDC) at Carderock, Maryland.

As the L/B is increased from the value of two assumed in Figure 11, the hump in the drag curve diminishes in height, and moves somewhat rightward, while the area of the side hulls subject to frictional drag grows. For ships of oceangoing size the net effect is that an SES with an L/B of five or six will be able to operate at speeds of 50 or so knots with significantly less power than one with L/B equal to two, but with substantially higher power the shorter and wider version will be able to reach higher speeds than a long, narrow one. If the maximum speed requirement were set at no more than about 60 knots and the cruising speed at 50 knots then an SES with L/B of five or six would probably be substantially less expensive to buy and operate than one with L/B of about two.

O'Neil mentioned this to Currie in the course of explaining some aspects of SES performance and when Currie showed further signs of interest, he obtained additional information from NSRDC and summarized it in a memo.[149]

In O'Neil's view this implied that the high L/B craft was likely to be a more practical vehicle for most purposes, since factors of both seal wear and crew tolerance were likely to limit practical speeds at sea to no more than 50 knots in most cases in any event. This further decreased the likelihood that the 2000/3000 ton SES could be a realistic prototype for practical ships and made it more of a technology testbed, and a very expensive one. Although the Navy specialists were wary of being too open with him, O'Neil sensed that they had generally similar views. He saw this as further confirmation that the Navy had unwisely committed itself to the costly and risky program to build a large SES before it had gained enough information to make prudent choices.

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[148] Memorandum DDR&E for ASN(R&D, "Summary of Understanding Concerning the SES Program," 13 Feb 1975, (See Appendix D); Testimony by Currie before House Armed Services Committee, 21 Feb 1975, (See Appendix D).

[149] Memorandum, CAPT M. C. Davis to O'Neil, "Comments requested on High L/B SES," 19 Mar 1974; Memorandum O'Neil for Currie, "Long, Narrow Surface Effect Ships," 3 Apr 1974, both (See Appendix D).

(To the [quite limited] extent that SESs have seen practical application since the 2000/3000 ton program, they have almost invariably had values of L/B substantially greater than 2.)

O'Neil also believed that there had been inadequate exploration of other types of novel vehicles in comparison with the SES. In essence the SES had been selected because it seemed to offer the best promise for meeting Zumwalt's personal desire for a 100 knot surface ship. Since there was no clear justification for 100 knot speeds, and little prospect that ships could regularly operate at anything approaching this speed, a more systematic and considered assessment seemed in order before further massive commitments were made.

What O'Neil had in mind was a broader and more up-to-date version of a well-known, early 1960s study evaluating a broad range of novel ship types in quantitative comparison by MIT professor Philip Mandel.[150] O'Neil convinced ARPA to fund Mandel to pursue the new study but there were limitations to what could be done in an academic setting. O'Neil and his superiors agreed that more extensive study was needed to open up consideration of alternatives. In connection with the negotiations over the future course of the large SES following Zumwalt's departure, Currie agreed to insert in his memo a paragraph directing the Service to conduct a comprehensive study and set aside $6.5 million for the task. The Navy accepted this as a part of the compromise and a constituency in support of it formed within the Service. Competent leadership was installed and many of the most able technologists contributed to the effort, which came to be known as the Advanced Naval Vehicles Concepts Evaluation (ANVCE).[151]

Understandably, the recommendations of the final report were not terribly bold since its authors could not commit the Navy to any major undertakings.[152] But it generated a good deal of valuable data, and the report process had a significant effect, as we shall see.

5. SES Prototype Size Debates and Program Review

Despite the Navy's efforts to avoid growth, the design weight of the SESs had crept up as designers addressed specific issues. By early 1975 it had grown from 2000 to 2200 tons, with a possible limit of 2800 tons using larger engines. Weight growth during design is a familiar phenomenon with many different kinds of vehicles. But at the same

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[150] Philip Mandel, "A Comparative Evaluation of Novel Ship Types," *Transactions, Society of Naval Architects and Marine Engineers* 70 (1962): 128-91.

[151] Memorandum DDR&E for ASN(R&D, "Summary of Understanding Concerning the SES Program," 13 Feb 1975, (See Appendix D).

[152] *Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project*, Summary, Volume 1 (Chief of Naval Operations, Dec 1979), (See Appendix D).

time the range-payload performance of the ship had fallen far short of original plans. In fact, unless the higher-powered engines were installed and the craft were operated at the higher gross weight, range would be little more than half of what seemed necessary for the missions envisioned. When Currie said as much in testimony before the House Appropriations Committee, the press and Congress took note and began to ask questions. The staff acted to dampen any furor.[153]

In light of the high-level interest, O'Neil probed further into size issues. He already knew that the scaling laws for gross performance operated in favor of larger SESs, which had to be weighed against increases in cost and risk. After discussions with the Navy and the contractors he reported favorably on larger sizes to Currie.[154] This led a protracted series of exchanges among the staff, the OSD leadership, the Navy, and members of Congress around the size issue.[155] While it seemed clear that a size of 3000 tons or greater would be best if the Navy were ever to build a class of operational SESs, it was difficult to see that the distinction between 2200 tons (as the Navy wanted) and 3000 tons (as Currie wished) was very significant for the prototype. That is, there were some advantages to the larger size but also some drawbacks and costs, and there was no clear basis for weighing them against one another. In discussing the question with people from all sides, it seemed to O'Neil that the intensity of feeling surrounding the issue sprang largely from a concern to win for victory's sake. Naturally, he bent his efforts to supporting the position taken by DDR&E, while trying to mute the controversy.

Per Currie's understanding with the SECNAV, a DSARC review of the preliminary designs and risk reduction results was to occur prior to approval for contract design and prototype construction. In preparation for the review, O'Neil spent some time in the autumn and winter of 1975-1976 going over technical reports and visiting organizations involved in design and test activities to gain an accurate picture of the situation.

In the end, Clements took sufficient personal interest in the SES to become directly involved, and this superseded the DSARC. We can only speculate about his reasons, and whether DDR&E and the Navy's dispute over size played a part in his decision. In any event, Clements (and some staff members, including O'Neil) visited some of the facilities involved for a brief personal inspection tour and 80 knot ride aboard one of the 100 ton SES test craft in April 1976. Following this trip O'Neil worked with the Navy, key OSD

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153 Testimony by Currie before House Appropriations Committee, 9 Apr 1975, (See Appendix D); Memorandum O'Neil for DD(TWP), "Summary of Responses to Queries on SES Sizing," 17 Jul 1975, (See Appendix D).

154 Ocean Control Weekly Status Report item (by O'Neil, to DDR&E), "Large SES Prototype," 30 Jul 1975, (See Appendix D); Memorandum DDR&E for O'Neil, "SES," 11 Aug 1975, (See Appendix D); Memorandum O'Neil for Currie, "SES," 22 Aug 1975.

155 Appendix D contains a number of relevant documents, dated between Aug 1975 and Apr 1976.

personnel, Currie, and Clements' staff to produce a decision memorandum that Clements signed on 21 May.[156]

The Navy issued an RFP to the two design contractors, Bell and Rohr, in June. In the autumn 1976 review of the Fiscal Year (FY) 1978 budget, the OSD Comptroller, for technical reasons, put forward an alternative that would have reduced FY 1978 program funding.[157] Word of this alternative leaked to the press and prompted a flurry of Congressional letters in support of the program.[158] In the event, the Comptroller was persuaded not to pursue the reduction and in mid-December of 1976 the Navy down-selected to a single contractor, Rohr Marine, and awarded it a detailed design contract, with an option for construction.[159]

6. A Sudden Chill; the Final Struggles

On 20 January 1977 a new president was sworn in and on the following day Dr. Harold Brown, the man who had served as DDR&E in the first years of McNamara's term, became SECDEF. The last time there had been a major shift in political leadership, 1969, the then-DDR&E had continued to serve for several years into the new administration. It was widely hoped among the DDR&E staff that Currie, who was well liked and respected, would remain in the job. But he departed promptly, leaving the post in the hands of the held-over deputy until Dr. William J. Perry took over on 11 April.

The Transition Team had requested lists of possible program cuts and O'Neil, with the blessing of his superiors, had included reductions to the SES program. In his major budget issues meeting, in his first days in office, Brown identified the SES as a candidate for cancellation.[160] Although Brown soon restored most of the SES cuts, program proponents in the Navy identified O'Neil as the source of the reduction proposal.

Budgets were under pressure due, in part, to high inflation, which was increasing the costs of defense programs. Perry had no experience to speak of with the SES or the surface Navy generally, but quickly grasped the essential points and decided to recommend cancellation in the fall budget review. Brown had no enthusiasm for the program either, but Congress would not go along and the program was restored.

As the budget review approached in the autumn of 1978, Perry sought a consensus position. O'Neil, who by then had been promoted to head of the office, was deputized to

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156 Complete decision package is in Appendix D.

157 SES Program FY 78 Budget Review presentation, 8 Nov 1976, (See Appendix D).

158 Sampling in Appendix D.

159 Robert Metz, "Market Place," *New York Times*, 13 Dec 1975, 68.

160 Memorandum SECNAV for SECDEF, "Surface Effect Ship (SES) Prototype Program," 1 Feb 1977, (See Appendix D). Also copy with marginalia in hand of Harold Brown, 2 Feb 1977.

negotiate with Navy officials and officers. The strong advocates on both sides were excluded and agreement on most points of fact was readily achieved. But everyone involved had organizational responsibilities that limited freedom to compromise on key points. With budget decisions quickly approaching, Perry and the Assistant Secretary of the Navy (Research, Engineering and Systems) (ASN(RE&S)) and the key members of their staffs met early in December to attempt to reach a consensus. While they did not reach one explicitly, the Navy leadership had lost much of its enthusiasm and ultimately did not strive very hard to reverse a decision that left the SES without support.[161]

Some of the people in the Navy who spoke with O'Neil attributed the lack of support within the Service, at least in part, to the ANVCE and what it was revealing about the limitations of the existing SES design by comparison with other options, and even more to what emerged from the ANVCE's effectiveness studies – or more importantly what had not emerged. And indeed, in later correspondence the ASN(RE&S) explicitly attributed the termination to what had been revealed by the ANVCE.[162]

Funding under the already-enacted FY 1979 budget covered work through the end of 1979. There were the inevitable efforts by the contractor, with the tacit encouragement of Navy personnel who remained committed to the program, to generate support for a last-minute rescue. While they did not ultimately prevail, their effort was sufficient to discourage any attempts by DOD to secure Congressional support for terminating the program before the end of the year. A stop work order was issued on 12 December 1979, followed by a 9 January termination. Unexpended balances were reprogrammed to support longer-term technology efforts.

January of 1981 brought a new administration planning a major defense build-up. Programs like the B-1 bomber were resurrected and the new DEPSECDEF suggested that perhaps the 3000 ton SES should be as well. But the new Navy secretary had strong ideas of his own and a large SES had no place among them. The new USDRE did not arrive until May, but in the meantime a new deputy had been confirmed and was acting for him; on the staff's recommendation, he backed the SECNAV and nothing was done to revive the program.[163]

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[161] Memorandum ASN(RE&S) for USDR&E, "Review of SES for FY 80 Budget," 28 Sep 1978, (See Appendix D); Memorandum O'Neil for Perry, "4 December Meeting on SES," 29 Nov 1978, (See Appendix D).

[162] Memorandum ASN(RE&S) for USDR&E, "Air Cushion Craft for Logistics Support Missions," 19 Nov 1981, (See Appendix D).

[163] Memorandum DEPSECDEF for SECNAV, "SES Program," 27 Feb 1981, (See Appendix D); Memorandum SECNAV for DEPSECDEF, "Surface Effect Ship (SES) Program," 16 Mar 1981, (See Appendix D); Memorandum USDR&E for DEPSECDEF, "Surface Effect Ship (SES) Program," 1 Apr 1981, (See Appendix D).

There were occasional further spasms of SES enthusiasm long afterward, but few went far. A handful of SESs have served in various roles, none more than a few hundred tons in size. In 2003 Raytheon proposed an SES as its entry for the 3000 ton Littoral Combat Ship (LCS) program, but it was rejected in favor of concepts offering lower risk and cost.

E. A Misconceived Program

The 2000-3000 ton SES was a tragedy in an Aristotelian sense – a program of a heroic nature that was brought low by its own internal flaws. The DDR&E staff (together with the PA&E staff) played the role of the chorus, keeping the flaws in view.

The key to the heroic quality of the SES was speed, and the all-but universal human search for it. Sailors have been seeking greater speed at sea for millennia, and to most it has a value that transcends sober calculation. The SES's promise of more than doubling the speed of ships gave it an inherently heroic character, making it a program that went beyond simply building another ship.

The heroic aura softened and obscured the program's flaws, at least for a time. But ultimately they fell into two categories: military end and technical means. The problem with the military end can be stated succinctly: no one could offer a convincing explanation of how the speed that the SES offered could be of special value in surface ship missions. The Navy's existing surface combatants could all reach speeds of 27 knots or greater, but the inherent limitations of sensors and weapons generally restricted their combat operating speeds to no more than 20 knots. Where higher speed was needed they relied on aircraft, 140 knot helicopters or fixed wing aircraft flying at 400 knots or more.

The Navy brought forward a number of contractor-prepared studies that strove to show how 80 knot speeds could offer a major advantage, but all withered under scrutiny by the PA&E and DDR&E staffs. Finally, in 1978, PA&E and its Navy counterpart agreed that a comprehensive review of the effectiveness analyses of the SES would be commissioned from a widely respected, independent expert on naval warfare analysis, Dr. Frank Bothwell. His findings were devastating:

> I have found no mission for which the surface effect ship offers a significant advantage over more conventional platforms—destroyers or submarines for some missions, aircraft for others. Almost invariably in any particular mission the SES is not the worst performer, but neither is it the best. In a few missions such as open ocean ASW [antisubmarine warfare] search or in barrier operations, a vehicle speed of 50 knots is desirable but only if it can be achieved at no more than a 50 percent increase in life cycle cost over the cost of conventional platforms. Only in case of reliable detection ranges well exceeding 100 miles does a higher

speed capability pay for some missions, and in these cases only if the life cycle cost does not exceed twice the cost of conventional platforms.[164]

This was essentially what the PA&E staff had been saying for years, with DDR&E concurrence, and what many people in the Navy had privately believed. The truth was only obscured by the heroic aura of the SES's speed and the effect it had exerted on Zumwalt and those who had been advising him. Once Bothwell confirmed the nakedness of the case for the ship, support for it evaporated.

Of course, in practice it has always been very difficult to foresee what the military value of innovations might truly be, simply because the course of conflict is so unpredictable. History is replete with examples of innovations that had initially been dismissed but later proved valuable. If we build it, some proponents insisted of the SES, applications will come. It was a thin argument for a major program, but it was difficult to dismiss conclusively, and it served to reinforce the heroic stature of the effort. But this argument rested on the technical and economic feasibility of the program.

The DDR&E staff took the lead in identifying the technical risk issues of the program and their implications. The early program documents presented the risks in vague, general terms that did not provide an adequate basis for decision. In the course of investigating the risks in the summer and fall of 1973, O'Neil could find no one in the Navy who could provide an overall synoptic view of them, or at least no one willing to discuss them. In essence, this critical system engineering effort was left to the DDR&E staff.

Very briefly, the critical technical issues identified by the DDR&E staff at the time of the DSARC IIA review at the end of 1973 were:

- **Operational lifetime of the seals, particularly at high speeds.** The life of the seals that had been used on ACVs and SESs up to that time was clearly insufficient for a transoceanic ship. The high speed and large size of the 2000 ton SES was bound to increase the stress and wear on seals.
- **Waterjet inlets and ducts.** The large SES would require more complex inlets and ducts than had been developed previously.
- **Ride quality and its effect on crew performance and health.** The SES follows wave contour closely and at SES speeds waves are encountered every few seconds, leading to constant severe jolts. Calculations showed that the ride of a large SES in a seaway would be different in character from that of a smaller one in lower waves, and there were no other vehicles with directly comparable ride

[164] Frank Bothwell, "An Evaluation and Synthesis of Several Analyses of Missions for the Surface Effect Ship," Tetra Tech, Inc., Nov 1978, (See Appendix D).

characteristics. The effects on humans were not well defined, but what was known gave cause for concern.

- **Ride control.** Contractors had proposed schemes for modulating the cushion to soften the ride, but there were uncertainties about their feasibility, effectiveness, and impact on speed and range.
- **Weight growth.** Weight growth was a concern in any weight-sensitive vehicle and particularly one with as little precedent as the large SES.
- **Drag and thrust margin in high seas.** Drag could be calculated with moderate confidence for calm seas, but grew increasingly more uncertain as seas mounted. It was certainly clear that drag would increase in high seas and that the thrust margin available for acceleration would diminish. At some critical sea state there would be insufficient margin of thrust over the primary drag hump to permit the SES to reach high speed at all.
- **Range and payload.** The range potential depended on weight, drag, and propulsive efficiency, all of which carried risks. And the drag risks increased with sea state. There was a clear risk that an SES caught at sea in a storm of even moderate intensity might not be able to reach port due to diminished range.

Many program advocates belittled the DDR&E staff's formulation of the risks, but all except those pertaining to water jets and inlets did prove seriously troublesome. Most remained matters of concern even five years later, when the program was terminated. What had been learned in some areas, particularly regarding the ride effects on the crew, was not at all reassuring.[165]

The uncertainties were made much greater and the solutions much more difficult by the very large jump in size, from 100 tons to 2000 (and ultimately 3000) tons. This was the result of impatience and a fear that the production of a mid-sized prototype would add time and cost to the program. Whether an intermediate prototype would have made a difference must remain a matter of speculation. It is notable, however, that subsequent to the termination of the 3000 ton SES, improved technology and design approaches did result in development of some moderately successful mid-sized SESs, and it is possible that an intermediate prototype would have brought improvements that would have made the large SES more attractive, at least in technical terms, and perhaps have provided information justifying development of a larger prototype.

[165] D.J. Thomas, et al, "Effects of Simulated Surface Effect Ship Motions on Crew Habitability—Phase II; Volume 5, Clinical Motion Medical Effects on Volunteers," Naval Aerospace Medical Research Laboratory Detachment, New Orleans, May 1977.

F. Lessons

1. Information and Communications

Although far from the largest or most important program that DDR&E dealt with in this period, the 2000-3000 ton SES provides a good illustration of how the organization functioned. There was one primary DDR&E action officer or staff specialist assigned to the program – O'Neil from 1973 to 1977, and later Mr. John McGough, under the supervision of O'Neil as the head of the office.[166] And as was always true, the staff specialist responsible for the program was also responsible for many other programs and could not focus all of his time on any one of them.

In dealing with a complex program such as the SES the staff specialist drew on a wide spectrum of resources within and beyond DDR&E. In the case of the SES there were others in DDR&E who were knowledgeable about the sensor, weapon, and propulsion systems proposed for it, and who had responsibility for some of the basic research and advanced development activities. The office director to whom the staff specialist reported had an overall understanding of the program in its broader context and was able to provide helpful guidance as well as direction, and the division director above him was also involved in higher level issues. The individuals who held the DDR&E post were themselves remarkably able to grasp the essentials of an enormous range of diverse programs and provide pointed and relevant feedback and guidance.

Others in OSD also contributed. As was usually the case, the PA&E staff was interested in the effectiveness and cost prospects of the SES and cautious about the risks involved in its technology. In this case their views meshed closely enough with those of the DDR&E staff to foster easy and productive working relationships, at least after O'Neil took over from the naval officer who had preceded him. In other cases more extensive discussions were needed to reach a consensus, but it usually was achieved. As we have seen, there had been notable cases in the 1960s when the two organizations disagreed, with counterproductive results, but this was rare in the 1970s.

The concerns of the Comptroller's staff were financial and managerial. O'Neil (who had studied management and finance, and had gained extensive knowledge of the DOD Planning, Programming, and Budgeting System (PPBS) in a previous post) maintained close relations with them, which was beneficial in improving both DDR&E and Comptroller management actions. Unfortunately, a few DDR&E people in other areas found it more difficult to establish good communications with their Comptroller counterparts, sometimes with disruptive results.

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166 McGough had joined the office as a result of a reorganization that merged portions of the staff and functions of the former Assistant Secretary of Defense (Installations and Logistics) with DDR&E under the new USDRE organization late in 1977.

Interactions with Service personnel, usually at the staff-to-staff level and often very informal and even somewhat irregular, played a very important role in the SES, as in many other programs. The Services had very extensive technical establishments with many people who had very solid technical knowledge. In the SES, as was very often the case, the Service authorities attempted to ensure that any communications would go through official channels, resulting in a very long delay and very narrow bandwidth filtering. But they enjoyed limited success in this. Like most DDR&E staff specialists, O'Neil and later McGough had wide contacts in the Services they dealt with and many of these contacts were prepared to be candid in matters they regarded as technical rather than programmatic in nature. Even in discussing program details, they might refuse to respond, but that could carry its own message.

Beyond the question of purely personal relations, however, the DDR&E staff had considerable leverage to gain the cooperation of Service personnel, if they used it well. Frequently, DDR&E was much more consistently supportive of investments in the long-term technical base than were the Services and the personnel of Service technical base activities tended to be favorably disposed toward the DDR&E staff as a result. Program offices were more closely supervised by Service higher echelons, but they recognized the value of good relations with the DDR&E staff and usually did not rigidly adhere to "channels" in communicating with it. In the case of the SES, this varied over time, depending both on the views of the program manager and the demands of the higher leadership.

There were occasions when the staff specialist or office head might find himself discussing a program with the top leadership of the Service; this happened several times on the SES. This usually came about when a top Service officer or official wished to exert influence, but if carefully managed such interactions could, and occasionally did, produce quite valuable results. In the SES case, such direct conversations played a role in the Navy's decision not to offer strong opposition to the decision to end the program in connection with the FY 1980 budget review late in 1978.

As in almost every case, industry was a very important source of information. Official communications with contractors flowed through channels, but there were also less formal channels. DDR&E personnel always had to be acutely conscious of anything that might impair competition or otherwise injure the public interest, but within those limits there was room for valuable interchange. On-site reviews often were particularly illuminating, despite close monitoring by program office personnel. For if DDR&E staff was adequately knowledgeable, they could learn much from seeing the hardware and drawings, and from the tenor of the responses from technical personnel. In the SES program there were opportunities for rides on a variety of test craft, sometimes at the controls, giving a (quite literally) visceral experience of ride quality as well as control issues.

It was not only the contractors who were involved in the program who could be helpful, but others in related fields. O'Neil, for instance, made a trip to England and gathered very valuable information on design and operation from personnel of various builders and operators of commercial and military ACVs there.

Finally, there were engineering articles and texts, technical meetings, short courses, and academic experts. O'Neil found considerable amounts of helpful technical literature and some of their authors, for example MIT professor Philip Mandel, were quite helpful on some points.

Not all these sources might be equally valuable in every program, but it was almost always worthwhile to cast a wide net. The staff specialist needed to be resourceful in seeking out information.

Inevitably, he rarely had any deep personal expertise in most of the issues involved in any particular program. But he had to have an adequate basic fund of relevant knowledge to be able to quickly and accurately assimilate new information, with relevant technical knowledge being the major but by no means the only factor. O'Neil's background, which combined knowledge of ship, aircraft, and antisubmarine warfare technical and operational matters, proved particularly well suited for the SES. But where there were gaps in the staff specialist's knowledge he needed to be prepared to fill them very quickly. In the worst case scenario the staff specialist not only lacks the necessary basic background but also the ability to recognize the gap in his knowledge and how to repair it. This had been a source of trouble in some cases in the 1960s, but by the 1970s DDR&E staff represented a broader base of knowledge and serious problems of this sort were quite rare.

As the SES program documents reproduced in Appendix D demonstrate, communications within DDR&E among the staff and between staff and leadership were often close, intimate, and informal. On critical issues, staff specialists might find themselves talking directly with their higher-level superiors, including the DDR&E himself, and sometimes the DEPSECDEF. Frequently these interactions occurred in response to events that demanded a relevant response on very short notice. In particular, it was frequently necessary to provide a cogent memo or point paper within a few hours. This happened repeatedly in connection with the SES, reflecting the high-level interest the program attracted.

Communications with the Congress represented a special category. Direct informal communications with Congressional staff members and particularly the committee staffs were often valuable for both sides. (At that time, the committees had no separate majority and minority staffs and the staffs, at least in principle, were supposed to be objective and nonpartisan.) DDR&E staff specialists and middle level executives often accompanied the DDR&E to meetings with members of Congress or testify before committees, and occasionally to testify themselves. In all this DDR&E staff members were supposed to be closely guided by the Legislative Affairs or Comptroller staffs, and usually were. There were some cases (not the SES) where DDR&E personnel "free-lanced" in their Capitol Hill communications, often to promote a particular program or point of view. While this could be productive in a narrow sense, it could also be very troublesome in the broader perspective, and could (and sometimes did) lead to a lot of trouble for DDR&E people involved.

2. Focus

One error by DDR&E on the SES involved its loss of focus on the truly central issues in 1975 when Currie and the Navy became mired in a dispute about the size of the prototype ship – 2200 tons (the Navy position) versus up to 3000 tons (as Currie insisted). For an operational ship the larger size would clearly be better, but it was not a clear-cut issue for the prototype. Thus from the DDR&E perspective, the dispute was a waste of time and political capital. O'Neil had brought the size issue to Currie's attention as a matter of full disclosure, but had failed to think through the implications carefully enough to point out clearly that it was a peripheral question for the prototype. Once the dispute commenced it took on a life of its own, with both sides reluctant to back down or compromise for what were basically internal political reasons. Currie "won," but it was a victory without significant substantive benefit.

3. Assessment

Clearly, this was not a successful program, but what about DDR&E's part in it? In playing a major role in killing it, did DDR&E serve or subvert the public interest? And if killing the program was the right thing, should DDR&E have moved to do it sooner?

In light of what is now known, based on experience with subsequent smaller SESs as well as engineering developments, it is virtually certain that the large SES prototype would have displayed many serious problems that would have severely limited its capacity to demonstrate worthwhile performance. To have corrected these problems would have required a second round of prototype development, or wholesale reconstruction of the original prototype, which would have been very unlikely to find support. And if the problems had been corrected (within the limits of what was technologically feasible) and if operational SESs had been built, the probability is very high that they would have provided only marginal improvements in capability (at best) at a high cost. Thus the cancellation of the program was unambiguously a service in the public interest.

This result was not clearly visible early in the program, but enough of it was clear by 1973 to amply justify its cancellation, or at least major restructuring. O'Neil's assessment was that Currie was very unenthusiastic about the program but not prepared to take a strong stand against it at that time. Leonard Sullivan, who headed PA&E from May 1973 to March 1976, was caustically critical of the SES, but did not press forcefully for its cancellation (and probably doubted that he had the political weight to succeed in the face of Navy opposition). In light of Zumwalt’s ardent support, and the strength of his position, it very likely appeared unattractive to become locked in a major battle over what was, after all, not really a major program at that point. There was always a price to pay for such struggles and it might have detracted from the ability of Currie and others to intervene elsewhere. While there can be no wholly objective and analytical basis for determining that this was the best choice, it was not unreasonable and certainly not definitively wrong.

On the whole, when assessed in terms of serving the overall public interest, it appears that the outcome of the SES was at least a moderate success for DDR&E (and for PA&E as well).

6. 1977 to 1981: DDR&E to Under Secretary of Defense for Research and Engineering (USDRE)

As previously noted in connection with the SES, 1977 brought a new administration to Washington and the Pentagon, and the new Pentagon administration, headed by former DDR&E Harold Brown, now SECDEF, brought change to DDR&E.

Brown brought in William J. Perry to fill the DDR&E post. Perry had served in the U.S. Army briefly just after the end of World War II and longer as an artillery officer during the Korean War before earning a Ph.D. in mathematics. He directed the electronic warfare laboratory for a defense contractor then started his own electronic warfare company. Most of his experience had been in strategic systems and he represented a return to the earlier tradition of DDR&Es.

Brown was dissatisfied with the management structure in OSD and particularly with the number of officials who reported to the SECDEF. He resolved this in part by deepening the organization, gathering more-or-less related functions under intermediate officials. In particular, all acquisition-related functions were brought under a new Under Secretary of Defense for Research and Engineering. When Perry was appointed to this new post, taking the title officially in October 1977, DDR&E was abolished and its staff and functions were absorbed into the new USDRE.[167]

One result was that Perry, still relatively new to the DDR&E job, gained a significantly broader scope of responsibilities. One of the ways he dealt with this was to focus his attention on a limited number of issues that he identified as being top priorities. Others issues were left largely to his staff. Since they lacked the authority to take official action, the organization's influence over acquisition eroded somewhat. At least, this seemed to be the dominant impression of the staff, who now for the first time heard division directors confess uncertainty regarding what the top leadership wanted on particular issues. Of course, some of this may only have reflected differences between Perry and Currie in terms of personal style.

Reflecting, in part, his background as well as Brown's concerns, much of Perry's attention as USDRE was focused on strategic programs. At the time major efforts to change strategic posture were underway, involving issues of both strategic and political

[167] Trask and Goldberg, *The Department of Defense, 1947-1997*, 37-8.

importance. This paper has addressed his actions with regard to the DSP, but for the most part we lack adequate materials for good case studies of others.

Rates of inflation in the late 1970s were exceptionally high for peacetime and prices rose particularly rapidly in many of the economic sectors that fed defense acquisition programs. This presented serious problems in financial management and ultimately politics. As DOD's acquisition chief, Perry was thrust into a leading position in dealing with them, absorbing a considerable share of his time and attention.

O'Neil, who had become head of the office dealing with naval tactical warfare programs, found himself fairly frequently in Perry's company. But at the staff level, most people saw a good deal less of Perry than they had of his predecessor. Given that the staff had expanded to cover the enlarged responsibilities, this was probably inevitable.

A new president and a change of administration in the Pentagon in 1981resulted in Richard D. DeLauer taking Perry's place as USDRE. DeLauer, a Ph.D. in aeronautical engineering, had served more than fifteen years as an aerospace engineering officer in the Navy. While in uniform he was deeply involved in missile programs and after leaving the Navy he joined TRW, Inc., as an engineering executive with a central role in the development of Air Force ballistic missiles. He was highly successful, becoming TRW's executive vice president before leaving to take the USDRE post.[168] DeLauer was best known for the "DeLauer Study," the 1977 report of a Defense Science Board task force he had headed that produced an especially broad and well-regarded set of recommendations for speeding, improving, and streamlining the acquisition process.[169]

While DeLauer's appointment continued the succession of exceptionally able and well-qualified leaders to hold the top acquisition post, his role was circumscribed by the views and policies of the new SECDEF. Caspar Weinberger sought to expand and accelerate defense acquisition and favored allowing the Services to do so with minimal direction from OSD, subject to budget control. In comments heard by the principal author at the time, DeLauer expressed particular frustration over what he sometimes felt were very poor decisions by Melvyn R. Paisley, the Assistant Secretary of the Navy (Research, Engineering, and Systems). Paisley was resistant to DeLauer's arguments and often insisted on taking positions that DeLauer believed were not in the government's interest.[170] Because Paisley had the strong backing of SECNAV John F. Lehman, Jr.,

[168] Ruben F. Mettler, "Richard D. DeLauer," *Memorial Tributes,* Vol 5 (Washington, DC: National Academy of Engineering, 1992), 74-79.

[169] *Report of the Acquisition Cycle Task Force,* Defense Science Board 1977 Summer Study, 15 Mar 1978.

[170] Paisley later pleaded guilty to charges that he had accepted cash and favors to rig contract awards and was sentenced to four years imprisonment. The prosecutors concentrated on a few instances where they had exceptionally strong evidence as a result of wiretaps and did not pursue all allegations of Paisley's wrongdoing, some of which stretched back before he came to the Pentagon. Thus it is not

who in turn could count on Weinberger's support, there was little DeLauer could do, as he privately explained to O'Neil after one particularly egregious case. While the situation was not so extreme in dealing with the other Services, USDRE's freedom of action was very circumscribed.

Thus by the early 1980s, the circumstances highlighted above had constrained USDRE's capacity to continue the legacy set by DDR&E in the 1970s of exercising a strong hand in deciding what was to be bought. PA&E's influence was similarly restricted, leaving the decision about what to buy largely to a balance between political figures such as Paisley and Lehman on the one hand and the internal politics of the Services on the other.

Just as DDR&E's influence in such matters had been far from complete, however, its successor's fall from influence also was incomplete, as the final case study shows.

A. Case 5: Forward Area Maritime Air Defense and the Relocatable Over-the-Horizon Radar (ROTHR)

1. Strategic Background: The Antisubmarine Warfare Experience

Until he became director of the naval warfare office in 1977, O'Neil had no direct responsibility for antisubmarine warfare (ASW) sensors and surveillance. Nevertheless, with technical work experience in underwater sound propagation and acoustic signal processing in industry prior to joining DDR&E, and service as a naval officer in antisubmarine warfare systems development, he had knowledge and an active interest in the program. In fact, he had long been deeply interested in the ASW mission and had studied the history of the antisubmarine campaigns in the two world wars, as well as the campaign analyses that were conducted in the 1970s by the Navy and PA&E.

In the campaigns against the German U-boat force in World War I and again in the first years of World War II, the Allies had been at a very grave disadvantage. The U-boat command could decide where to strike, while the ASW forces; not knowing where this might be (owing to the difficulties of detecting the submarines) had to try to defend everywhere. As a result, U-boats usually enjoyed the advantages of surprise and, with the development of wolf-pack tactics (*Rudeltaktik*), the concentration of force that enabled them to inflict disproportionate causalities despite the very great Allied investment in ASW forces. Convoying helped somewhat, principally by making it harder for the

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possible to say whether his defiance of DeLauer was motivated by sincere disagreement, a desire to strut his power, or pecuniary considerations. Regarding Paisley and his crimes see Andy Pasztor, *When the Pentagon Was for Sale: Inside America's Biggest Defense Scandal* (New York: Scribner, 1995), and Irwin Ross, "Inside the Biggest Pentagon Scam," *Fortune*, Jan 11, 1993, pages 88 et seq.

submarines to find targets, but shipping losses remained perilously high through the first three years of the Battle of the Atlantic in World War II.[171]

Over the course of the first half of 1943, the advantage swung very sharply in favor of the Allies. Indeed, between March and May, the loss exchange rate fell from 8 merchant ships sunk per U-boat lost to 0.56.[172] The first figure, if continued, would have spelled grave trouble for the Allies, while the second accurately foretold ineffectiveness and doom for the U-boat force. There were multiple factors at work in this transformation, but the most striking involved surveillance of U-boat positions and the means to exploit surveillance knowledge. The surveillance was provided by communications intelligence (COMINT), including traffic analysis, direction finding, and cryptology, which taken together could intermittently provide gross positions for some U-boats. Because these were fleeting and not very accurate it was essential that they be prosecuted very quickly by systems able to rapidly search out a considerable area of uncertainty, a need filled principally by long-range, land-based patrol aircraft.[173] Even though COMINT positions were imprecise, generally inaccurate and rarely obtained, and even though aircraft were not always available for prompt prosecution, the result was a very distinct increase in U-boat sinkings. Moreover, even when the U-boat could not be destroyed, the warning provided by COMINT often allowed the target convoy to evade the attack, or better defend against it.

The Soviet submarine force during the Cold War era was more cautious about radio transmissions than the U-boats had been and much less could be learned from COMINT. But discoveries made by OSRD scientists in World War II provided a basis for long-range acoustic detection systems. Faced with the threat of Soviet ballistic missile submarines, development pressed forward in the 1950s. The result was deployment of the first large-scale acoustic surveillance system, Sound Surveillance System (SOSUS).[174]

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[171] Despite limitations, the best overall analytical treatment remains Charles M. Sternhell and Alan M. Thorndike, "Antisubmarine Warfare in World War II," OEG Report No. 51 (Washington, DC: Operations Evaluation Group, 1946). The authors were not free to discuss the effects of COMINT and it has never received analytical attention on the scale its importance merits, but Brian McCue, "A Chessboard Model of the U-boat War in the Atlantic with Applications to Signals Intelligence," *Naval Research Logistics* 52, No. 2 (March 2005): 107-36, provides considerable insight. From an analytical perspective, the most useful popular account is V. E. Tarrant, *The U-boat Offensive, 1914-1945* (Annapolis: Naval Institute Press, 1989).

[172] "Evaluation of the Role of Decryption Intelligence in the Operational Phase of the Battle of the Atlantic," OEG Report 68/SRH-36 (Washington, DC: Operations Evaluation Group, 1952), Declassified, 1-2.

[173] The most numerous and effective of these were Consolidated B-24 Liberator heavy bombers, diverted over staunch Air Force objections from employment as bombers.

[174] Gary E. Weir, "Sosus, the Navy, and Bell Labs," in *Providing the Means of War: Historical Perspectives on Defense Acquisition, 1945-2000*, ed. Shannon A. Brown (Washington, DC: U.S. Army Center of Military History and Industrial College of the Armed Forces, 2005). For more detail about

The Navy's patrol aviation community worked with the same S&T community to obtain systems that would permit effective prosecution of SOSUS detections (which were frequently inaccurate by tens of miles owing to the vagaries of long-range sound propagation). But by the late 1960s, good results were starting to be achieved.

Although developed for strategic defense, the combination of undersea surveillance and long-range ASW aircraft was equally effective for protecting forces at sea from submarine attack. The Navy also invested heavily in tactical ASW forces for defense of convoys and task groups. But war games consistently showed that land-based patrol aircraft, guided by undersea surveillance, provided more effective defense at lower cost. The Navy, nonetheless, preferred the tactical forces, which it regarded as more flexible, and DDR&E and PA&E repeatedly felt compelled to intervene to assure adequate funding for surveillance and land-based aircraft.

2. The Problem of Soviet Strike Forces

O'Neil observed in the 1970s that while a considerable measure of cost-effective area defense had been achieved against submarines, defenses against air attack remained almost exclusively tactical. The strike aircraft of the Soviet Navy's *Aviatsiya Voyenno-Morskoyo Flota* (AV-MF) or naval air aviation did not have the range of its nuclear submarines, but large and critical areas lay open to AV-MF attack. The force was being strengthened with more modern and capable aircraft, armed with large air-to-surface missiles. The mobility of its aircraft gave the AV-MF the potential to deliver a much more concentrated blow than submarines could, which complicated the defense picture and demanded large investments for every critical target. The AV-MF command could amass its forces to attack surgically, while the United States and its allies had to try to mount strong defenses everywhere at all times. In short, the offense enjoyed a marked advantage because it was impossible to provide adequate protection to not only the ships but also the critical littoral shore installations lying within AV-MF's potential reach.

Providing forces and systems for defense of ships was a naval responsibility, while the Air Force, Army, and Marine Corps divided responsibilities for shore installation defense. Each had some right to call upon support from the others and from intelligence sources. Among the allied forces, responsibilities were similarly divided. No one had overall organizational responsibility for systems to counter the threat.

The unified commander and NATO regional commanders did have overall operational responsibility within their areas. O'Neil visited their headquarters to inquire about their views and concerns, in most cases getting to speak with the commander himself as well as his staff. O'Neil was a reserve officer, attached to the staff of the U.S.

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the system and its performance see Edward C. Whitman, "SOSUS: The 'Secret Weapon' of Undersea Surveillance," *Undersea Warfare* 7, No. 2 (Winter 2005).

Atlantic Fleet commander, who also commanded the joint Atlantic Command as well as NATO's Atlantic region. In this capacity he had conducted an in-depth study of the command's architecture for operational intelligence to define needed improvements. Based on this experience, it was clear to him that the top-level operational commanders were concerned about the AV-MF threat but could see little to do beyond attempting to optimize allocation of their inadequate defensive forces. While some thought was given to strikes on AV-MF bases, this option presented serious political as well as military issues.

3. Proposed Land-based Patrolling Surveillance and Intercept Aircraft

Operating on the general principle that DDR&E should seek technological innovations to meet needs, O'Neil began to look for solutions to address the AV-MF threat. The Air Force was completing development of its Airborne Warning And Control System, and O'Neil's thoughts turned to a similar system, optimized for maritime air search (which permitted simplification of the radar), mounted aboard an aircraft optimized for long-endurance patrol – an aircraft equipped not only to detect AV-MF formations but to attack them with long-range missiles. He elaborated on the details and proposed variations under several different titles.[175]

While some individuals within the Navy expressed interest and even support, the Service's institutional response was sharply negative, and it pushed to ensure that Congress did not give the proposal serious consideration, relying on Capitol Hill staff members who had ties to the Navy. There was little specific substance to the Navy's criticisms, but as O'Neil discussed his ideas with colleagues and thought more deeply about them, he began to see important flaws.

The most fundamental defect was that the system did not do enough to reverse the AV-MF advantage. Because of its high altitude and the size of the radar target presented by a large group of AV-MF strike aircraft, each defending aircraft could reasonably expect to cover an area of several hundred thousand square miles with radar surveillance, but the area of concern amounted to several million square miles. Simple analyses suggested that a large force of highly capable patrolling aircraft would be necessary to cover the critical areas on a sustained basis and only a very small fraction of the force would likely have an opportunity to engage an AV-MF attack, meaning that force productivity would be modest.

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[175] O'Neil memorandum for the record, " 'Land-Based Support Aircraft' Program (U)," 7 May 1976; O'Neil memorandum for distribution, "Land-Based Multi-purpose Naval Aircraft (LMNA) Concept," 15 September 1976; O'Neil memorandum for the record, "Considerations in the Design and Operation of Long-Range Offensive AAW Patrol Aircraft," 8 June 1977; O'Neil, "Land-Based Aircraft Options for Naval Missions," Society of Automotive Engineers paper 770965, Aerospace Meeting, November 14-17, 1977. All in Appendix D.

Something better was needed. In particular, it appeared that there was a need for genuine broad-area surveillance as well as interception forces with enough mobility to concentrate in force against the targets it detected. The major question was how to provide the surveillance.

4. Broad-area Surveillance

When O'Neil took over as the director of the naval warfare office late in 1977 (after Cann's departure to take a senior Navy post), he had a vacancy to fill, and he hired David L. Anderson, an electronics engineer who had a background in advanced technology reconnaissance, surveillance, and sensor systems. After discussing the AV-MF threat, Anderson suggested looking at OTHR technology, particularly skywave OTHR.[176] Skywave OTHR uses the ionosphere as a mirror, to reflect radar signals back down to earth at distances up to 2500 nautical miles (nmi) from the radar transmitter.[177] To do so, it must operate in the high frequency radio band, at frequencies of three megahertz (MHz) to thirty MHz, resulting in wavelengths of ten to 100 meters.[178]

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[176] OTHR technology is overviewed in a number of survey articles, such as James M. Headrick and J[oseph] F. Thomason, "Applications of High-frequency Radar," *Radio Science* 33, no. 4 (Jul-Aug 1998): 1045-54, or, more succinctly, James M. Headrick, "Looking Over the Horizon," *IEEE Spectrum* 27, no. 7 (Jul 1990): 36-39. Surface wave OTHRs (SWOTHR) are shorter range systems, also at high frequency, which utilize different propagation phenomena.

[177] The ionosphere is a layer (or series of layers) at the far reaches of the upper atmosphere, roughly 50 nmi to 500 nmi above Earth's surface. It draws its name, and its unique electrical properties, from the fact that solar radiation ionizes the thin atmospheric gasses, forming a plasma of free electrons.

[178] Historically, HF stood for "high frequency," because megahertz frequencies were at the upper end of what the technology of the time (early 1900s) would permit. Today, of course, vastly higher frequencies are routinely used, but the conventional designation remains.

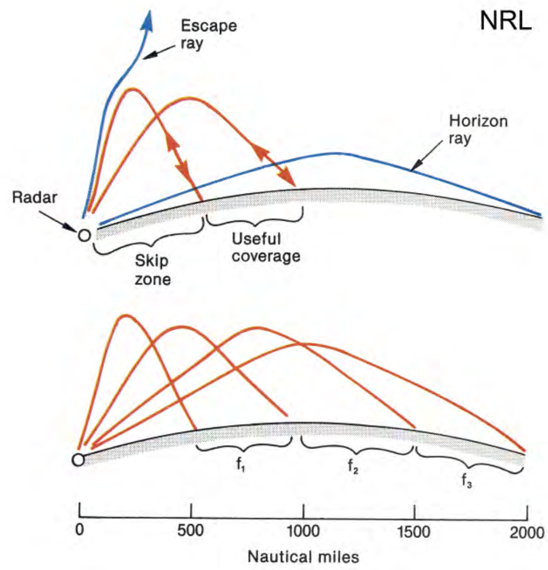

Figure 12. Schematic Diagram of Skywave Paths, with Greatly Exaggerated Vertical Scales

After becoming familiar with the physics and engineering principles of OTHRs O'Neil concluded that the technology might have potential for broad-area air surveillance over ocean areas (as well as surface surveillance). He and Anderson communicated their interest to various government and industry organizations involved in OTHR work and received a variety of briefings.[179] Perry was kept informed and expressed some interest.

OTHR development had a somewhat checkered earlier history. Work on these systems had started at the Naval Research Laboratory (NRL) in the 1950s and late in the decade NRL completed a successful test and demonstration system. Various OTHRs had been deployed for classified intelligence collection missions since the early 1960s, but, of course, they were not widely known. A major late 1960s effort to keep watch over the Warsaw Pact areas opposite NATO's Central Region with the AN/FPS-95 OTHR (codenamed COBRA MIST) in England was unsuccessful. Its failure, never satisfactorily explained, soured many on the technology, but by the late 1970s a new design of OTHR, the AN/FPS-118, was under development to meet demands for detection of Russian bombers or cruise missiles approaching North America.[180]

The AN/FPS-95 and AN/FPS-118 were both massive, powerful systems that could only be installed in large fixed sites. This was acceptable to meet permanent, fixed needs, but O'Neil believed that a less costly and more flexible system was required for tactical

179 Two samples are included in Appendix D.

180 Joseph F. Thomason, "Development of Over-The-Horizon Radar in the United States," in *Proceedings of the International Conference on Radar (RADAR 2003) Held in Adelaide, Australia on 3-5 September 2003* (IEEE, 2005) http://handle.dtic.mil/100.2/ADA445505.

ocean surveillance. He discussed this with various people involved in OTHR development and drew a response from Lawrence E. “Larry” Sweeney, Jr., who headed an OTHR program at SRI, Inc.[181] Sweeney’s group had an experimental OTHR called the Wide-Area Research Facility (WARF) that he and others in the group had designed and built in the late 1960s to test techniques and applications.[182] After examining the issues described by O’Neil, Sweeney concluded that it would be possible to pack all of the components of an OTHR designed along similar lines, to be carried on a ship of modest size or on several C-5 loads to be assembled at a new site. After some discussion, O’Neil and Sweeney labeled the concept the *relocatable OTHR*, or Relocatable Over-the-Horizon Radar *(ROTHR)*.

O’Neil discussed his investigations with Navy officials and officers, who showed varying degrees of interest. In the meantime, the Navy was pursuing other initiatives that eventually crossed paths with what O’Neil was doing.

Earlier in the 1970s, the Navy had proposed a space-based radar (SBR) for detecting larger surface ships, under the code name CLIPPER BOW. In 1979, however, Congress killed the program as concern was growing that the limited mission could not justify the cost of the program.[183]

In 1980, Vice Admiral Gordon R. Nagler took over as head of Command and Control (OP-094) in the Office of the Chief of Naval Operations and began to pursue what was called the Tactical Surveillance System (TSS). TSS was a more ambitious SBR with the ability to detect and track aircraft as well as ships which, it was hoped, would be enough to justify its cost. From O’Neil’s standpoint, the project offered the attraction that Nagler could better gain Navy support than he could.

But while the cost of the SBR concept was not well defined it was clear that it would involve great expense. An SBR constellation would give regular periods of brief coverage throughout a band of latitudes centered on the Equator. The angular extent would depend on the orbit as well as the characteristics of the radar.[184] To reduce the intervals between satellite revisits enough to be tactically useful for tracking aircraft it

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[181] SRI, which originally stood for the Stanford Research Institute, is a non-profit technology institute serving government as well as other clients.

[182] James R. Barnum, “Ship Detection with High-Resolution HF Skywave Radar,” *IEEE Journal of Oceanic Engineering* OE-11, no. 2 (Apr 1986): 196-209.

[183] Norman Friedman, *Seapower and Space: From the Dawn of the Missile Age to Net-Centric Warfare* (Washington, DC: Naval Institute Press, 2000), 178. It should be noted, however, that this source must be treated with a great deal of caution. The author, an outsider who never served in the Navy nor worked in government, had to rely on very fragmentary and sometimes deliberately misleading public sources in researching the subject and gets much of it wrong as a result.

[184] There are possible alternative orbital schemes but they would involve still greater expense and were not pursued.

would be necessary to have a large number of satellites in the constellation, and each satellite would cost tens of millions of dollars simply to launch, to say nothing of the hardware and support costs. Moreover, O'Neil's analysis convinced him that the SBR concepts under consideration in TSS would run substantial risks of serious vulnerability to certain quite feasible enemy countermeasures, and he also identified other significant operational problems.

As a result of pressure from O'Neil and others in OSD, TSS became the Integrated Tactical Surveillance System (ITSS), with the first step being development of an architecture that drew optimally from all the possible alternatives, including airborne early warning (AEW) aircraft and OTHRs as well as SBRs. In addition, various improvements were incorporated in the ITSS concept in an effort to address O'Neil's criticisms. Ultimately the study contracts went to three aerospace firms that made satellites but had no experience with any of the other systems, leaving little doubt about the real intention. The contractors dutifully solicited information from those with knowledge of alternative systems, but O'Neil's and Anderson's discussions with them showed a strong orientation toward satellite solutions, as might be expected.

While O'Neil found Nagler personally affable, he was resistant regarding the development of ROTHR. O'Neil suspected that this was due to mission competition with Nagler's preferred SBR solution.

As 1980 wore on, O'Neil found a good deal of interest in the ROTHR at high levels, including a query from SECDEF Brown. But the election in November resulted in a turnover of the presidency and with it a completely new set of top officials in the 1981. And as previously discussed, SECDEF Weinberger made it clear that he looked to the Services, rather than OSD, for leadership in innovation.

The impetus behind the SBR increased in 1981 as officials in the Air Force agreed with Nagler and the top Navy leadership that a common system would serve both their needs. O'Neil and Anderson, however, remained very skeptical that such a system could ever come to fruition, given its costs and problems. The two continued to campaign for ROTHR as the mainstay of air surveillance against the Soviet long-range naval strike forces. The new USDRE, DeLauer, proved receptive and with his tacit approval O'Neil published a proposal for a network of ROTHRs coupled with AEW aircraft to fill temporal and spatial gaps in coverage.[185] While this attracted broad attention and some scattered support even among senior naval officers, the response of Lehman and Paisley,

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[185] O'Neil memo for distribution of 14 Aug 1981, with paper, "Over-the-Horizon (OTH) Radar for Navy Tactical Surveillance." Merrill I. Skolnick, head of the radar division at the Naval Research Laboratory (which had led the early development of OTHR technology) was pleased with O'Neil's advocacy, but chided him for underrating the technical potential of OTHRs. O'Neil had done so deliberately, however, calculating that it would make it easier for him to discredit any attacks on technical grounds.

now SECNAV and the Assistant Secretary of the Navy (Research, Engineering and Systems), was negative in private.[186] Senior Air Force officials also joined in criticizing it. Given Weinberger's views on Service primacy, this seemed to doom the ROTHR.

But there remained other places to look for support. DeLauer brought the ROTHR to the attention of British counterparts who were concerned about the air threat not only to ships but to Britain itself from Soviet aircraft flying down the Norwegian Sea. A cooperative program was established to investigate the feasibility of a north-looking OTHR sited in Britain under the code name COLD WITNESS.[187] The concept was also disclosed to the Japanese, who were interested and eventually took up the idea.[188] (Neither effort proceeded once the end of the Cold War eased concerns about Soviet air threats.)

O'Neil meanwhile worked to inform the operational commanders of the opportunities offered by the ROTHR. He was familiar with their operations and points of view, in part on the basis of his naval reserve experience. Thus he was well aware of the information concerns of these commands and able to explain how the ROTHR could fill important needs.

In May 1983 a mutual contact arranged for O'Neil and Anderson to brief Admiral William J. Crowe, Jr., then about to assume command of U.S. forces in the Pacific (USCINCPAC). O'Neil and Anderson knew that there was a prominent civilian on the Pacific Command staff who knew about OTHRs and believed that they would meet an important need for the command. So they were encouraged when Crowe showed interest at the end of their short briefing. Indeed, soon after assuming command in July, Crowe sent a message to the DEPSECDEF expressing an urgent need for ROTHR.

Although SECDEF Weinberger was part of a gathering consensus that the unified commanders, like Crowe, should have a major say in operational requirements, they rarely expressed any that were actionable because the nature of their commands tended to focus their attention on near-term needs that could not be met through new developments, and because they lacked the staff support necessary to formulate their needs clearly and convincingly. But this was a clear, actionable requirement and Weinberger directed the Navy to fill it. After a fairly nominal amount of grumbling and resistance the Navy established what became the AN/TPS-71 ROTHR program.

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[186] Officers on their staffs quietly kept O'Neil informed of what they said and did.

[187] "U.K., U.S. Cooperate in Over-the-Horizon Radar Program," *Aerospace Daily*, 9 Jan 1985, 47. The program's existence had been compromised through an accidental disclosure in Britain in 1984. See "Classified List Found; Britain Starts Probe," *Boston Globe*, 22 Mar 1984, 13.

[188] Kensuke Ebata, "USA, Japan Reveal OTH Radar Sites," *Jane's Defence Weekly*, 8 Feb 1986, 177.

5. Interceptors

While the ROTHR appeared to offer a good solution to the surveillance problem, forces to close with and intercept the AV-MF raids were needed to take full advantage of the information it would generate. The ideal solution would be an aircraft like the Lockheed YF-12, the proposed fighter variant of the SR-71 Mach 3 reconnaissance aircraft. Aircraft of this class would have the speed and range to reach and intercept AV-MF raids anywhere in the forward maritime regions.

Figure 13. Lockheed YF-12 Supersonic Interceptor Prototype

Originally, the F-12 program had been terminated because the limited Soviet strategic bomber threat could not justify the high costs of such a force, and realistically neither could the air threat in maritime areas. When O'Neil queried manufacturers he was not surprised to learn that while there were prospects for somewhat improved performance there were none for significantly reduced cost.

Aircraft carrier air wings included substantial forces of interceptors, with the especially capable F-14A then coming into service. If provided with good warning and surveillance, a carrier could mount a very strong interception. But carriers would often not be available, and in any event would generally reserve most of their fighter strength for self defense or to support their own strike operations.

The U.S. Air Force (and the air forces of U.S. allies in the maritime regions) had responsibility for air defense on a regional basis, and stationed interceptor forces at some forward bases. But except where there were other needs, generally these forces were not only small but equipped with some of the oldest and least capable fighter aircraft in the inventory.

In the fall of 1982, during the review of the FY 1984 budget, various elements of the OSD staff joined in calling attention to inconsistency and overlaps in the Air Force and

Navy programs affecting air and surface surveillance in maritime areas. This resulted in a DEPSECDEF decision to form an ad hoc review committee, with Service and OSD representation, chaired by O'Neil. The Navy protested vehemently, arguing that "The Committee's authority and scope … constitute an infringement on traditional Service roles and run counter to the … policy of increased authority and responsibility to the Service secretaries."[189] However, the DEPSECDEF coolly replied that

> The Broad-area Surveillance Executive Committee (BSEC) was established strictly as a mechanism to permit both the Navy and Air Force to play full and productive parts in a cluster of programs which transcend the traditional roles of either Service. The Executive Committee is a collaborative organization with no permanent staff and only the absolute minimum authority necessary to assure effective execution of these inherently cross-Service programs. The BSEC is the best method to ensure that this very important job is accomplished.[190]

In stressing its "traditional role" the Navy had unwittingly given ammunition to the OSD staff, which argued that this was an area where DOD could not afford to be mired in tradition.

Unexpectedly, the BSEC had more impact on interceptor than surveillance forces when the question of surveillance reached a climax in the first part of 1983 with little BSEC intervention. The ITSS studies reported at the end of 1982 and, just as they had been structured to do, proposed an SBR system as the solution.[191] They did not find a basis for ruling out ROTHR concepts, and the Navy decision-makers were not quick to decide on what, if anything, they wished to do. The great cost of the SBR system was a consideration even in those years of rapidly increasing acquisition budgets. Before the Navy reached its decision, Crowe's demand for ROTHRs hijacked the discussion. There was an attempt to see if he could be deflected with a promise of SBRs in the future, but he insisted on ROTHRs, which not only appeared be a nearer-term, more affordable solution, but had the attraction of coming under the control of the unified commander without having to go through a higher-level tasking mechanism (as O'Neil had not omitted to point out in briefing Crowe earlier.) The ultimate result was OTHRs rather than SBRs.

In the meantime, O'Neil had used the BSEC as a theater for exchanges among the various elements of the Navy and Air Force, with operational commander inputs,

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[189] SECNAV memo for DEPSECDEF, "Broad-Area Surveillance Systems for Sea Lane Defense," 14 Feb 1983, (See Appendix D).

[190] DEPSECDEF memo for SECNAV, "Broad-Area Surveillance Executive Committee (BSEC)," 7 Mar 1983, (See Appendix D).

[191] "Navy Mulls Space-Based Radar, Transportable OTH Radar Programs," *Aerospace Daily*, 7 Jan 1983, 33-4, (See Appendix D).

regarding the state of area air defenses generally in maritime areas. The picture that emerged was distinctly chaotic and, as he pointed out to the Service leadership, potentially quite embarrassing to the Air Force, to say nothing of its potential to compromise the strategic position on the maritime flanks in the event of conflict. After some ruminations, the Air Force responded with changes in force allocations and command structure that did much to close the gaps and provide forces that could utilize information from OTHRs and other sources to inflict serious casualties on AV-MF raids.

The BSEC's formal report became mired in coordination and finally lapsed. Nevertheless, the BSEC had accomplished its real purpose.

6. AN/TPS-71 Program

When O'Neil left USDRE in mid-1984 to return to industry, Anderson took his place as office head and continued to oversee the ROTHR program until it was well established. In 1987 there was a Congressional attempt to cut funding (with exceptionally specious justification) but Crowe, by then the Chairman of the Joint Chiefs of Staff, successfully intervened to preserve it. The Pacific Command planned to install two OTHR sectors in the Aleutians and three in Guam, in addition to Japanese sites, to provide comprehensive air and sea surveillance in the Western Pacific. There was also a plan to install a system in the United States to look south over the Caribbean. A total of nine systems were to be procured at a cost of about $75 million each. With site preparation and installation the total cost came to roughly $100 million per system, with operation costs on the order of $10 million per year. Once surveillance testing in the Caribbean was complete, the first system was relocated to Amchitka Island, Alaska in 1989-90.[192]

In principle, the ROTHR resembles the WARF. Total transmitter power is a modest 200 kW, with the transmitter array occupying an approximately fifty acre site. The receive array consists of 372 pairs of relatively simple vertical monopoles, arrayed in a double line 2.7 km long. About 100 acres is needed for a receive site, which should be separated by roughly 100 nmi from the transmitter for best performance. As completed the radars had an angular scan width of up to 90 degrees or more, although this could be increased, with some falloff in performance at the most extreme angles. Environmental conditions affecting propagation can vary with location, azimuth, season, and time of day, but as a broad generalization it is possible to gain reliable coverage at ranges from 500 nmi to 1800 nmi from the receive site. Within the 64 degree fan of coverage over this range band the ROTHR, as completed, had the capability for focusing at any one time at

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[192] David Hughes, "Navy Installs ROTHR System in Alaska to Protect Battle Groups in Pacific," *Aviation Week & Space Technology*, 27 Nov 1989, 69, 73, 75; "Virginia ROTHR System Covers Caribbean Drug Smuggling Routes," *Week & Space Technology*, 27 Nov 1989, 76, 80.

a set of dwell illumination regions covering roughly one third of the whole sector. These can either be set to stare at areas of special importance continuously or stepped through the sector for comprehensive search, dwelling at each point for a period long enough to detect and initiate track on any targets present.[193]

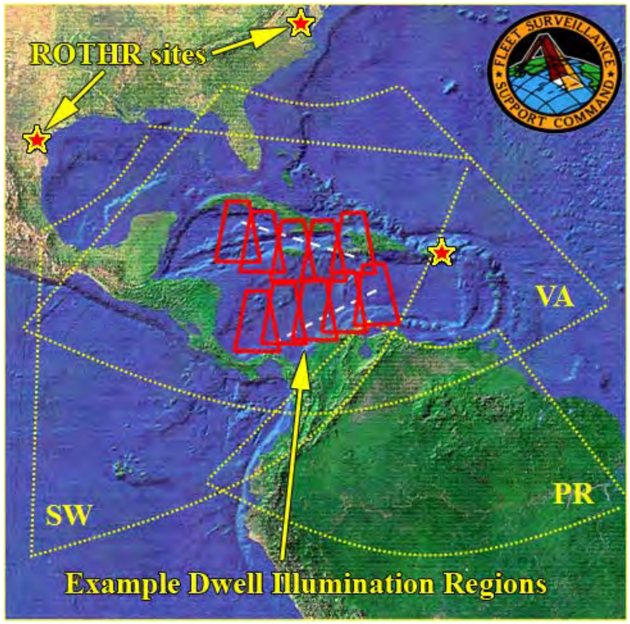

Figure 14. Present Normal Operational Coverage of the Three ROTHR Systems

Relocating a ROTHR is a substantial but not massive undertaking. Before relocating, the sites must be acquired, leveled, surveyed, and foundations for equipment poured. If engineer units are available this will require a few weeks on an expedited basis. The equipment occupies on the order of 60 twenty-foot container equivalents with a total weight of approximately 600 tons. It may be lifted by a small ship, as a fraction of the load on a larger ship, or by an airlift effort of roughly fifty C-17 mission equivalents. A total of less than a month is required to dismantle, pack up, unpack, and erect the equipment at a prepared site, plus transit time. If the sites do not have power, additional lift will be needed for base-load generating capacity, plus fuel. (Emergency generation capacity is included as part of the ROTHR equipment.) Similarly, it may be necessary to transport personnel facilities, although this need is minimized by the small onsite crew requirements. Most operational functions can be performed remotely at a convenient location. Total cost to prepare a site and relocate, a minimum of $25 million, will vary with needs and situation.

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[193] James M. Headrick and Joseph F. Thomason, "Naval Applications of High Frequency Over-the-Horizon Radar," *Naval Engineers Journal* 108, no. 2 (May 1996): 353-62.

Figure 15. ROTHR Sites: Transmit (left) and Receive (right)

The end of the Cold War resulted in removing the Amchitka radar back to the United States for further testing. Encouraging results in the counter-drug surveillance role brought a decision to keep all three production ROTHRs in commission, using largely civilian manpower, for continuing counter-drug operations. Many drug smuggling vessels and aircraft are much smaller than military counterparts and face fewer tactical constraints, making them harder to detect than the targets the ROTHR was designed to detect, but the system has been adapted with good success.[194]

The AN/TPS-71 involved too little investment to qualify as a Major Defense Acquisition Program (MDAP). As a result there is no Selected Acquisition Report (SAR) data on how well it met its cost goals.

7. Lessons and Implications

It appears quite unlikely that the Navy would have acquired the ROTHR without the efforts of the USDRE staff and the quiet support of their superiors. It is one example, out of a number, of the benefits of DDR&E/USDRE initiative. It may not be a typical example because details varied a great deal from one program to another, but it clearly was part of a general spectrum.

The distinct contribution of USDRE was not in the technology of the ROTHR – that was entirely the work of others, principally NRL and SRI, with refinements and engineering by Raytheon. But it was USDRE that made the crucial connection with a military need – not a formally stated operational requirement, but a mission concept that was clearly highly valuable – and that worked with technologists to develop a system

[194] Fleet Surveillance Support Command briefing created 19 Apr 2001, (See Appendix D); Marissa Kaylor, "Forces Surveillance Support Center Celebrates 20 Years," Fleet Public Affairs Center Atlantic, 10 Aug 2007.

concept that filled the need effectively and economically. And it was USDRE that brought this potential forcefully to the attention of allies and unified commanders at a time when the Services were distracted by other issues. This was a direct outgrowth of the position of DDR&E/USDRE at the crossroads of technology and operations and its ability to influence decisions. Even after changes in administration policy had sapped USDRE's power and, in principle, deprived it of a mandate to innovate, it still had the inherent capacity to influence decisions simply because of its position in the DOD hierarchy and, above all, because of the quality of its staff.

It might seem that the intervention in Air Force allocation of interceptors and command arrangements had nothing to do with DDR&E/USDRE responsibilities, since it involved no technology considerations at all. But from the DDR&E/USDRE's standpoint this was simply one outgrowth of its systems engineering analysis of the maritime air defense function, and a component of the system architecture that resulted from it.

By the end of the 1980s, the efforts of DDR&E/USDRE over the preceding two decades had gone far to constrain Soviet naval forces. As their doctrinal publications repeatedly emphasized, the two primary striking arms of the Soviet Navy were the submarine force and the AV-MF strike aircraft. The surveillance-and-interception mission systems structures pioneered by DDR&E/USDRE could not render them completely impotent, but they would have very severely constrained their ability to affect the overall course of a conflict.[195]

[195] William D. O'Neil, *Technology and Naval War* (Washington, DC: Department of Defense, Nov 1981), (See Appendix D).

7. Lessons and Recommendations

A. Effectiveness of DDR&E in the 1970s

The case studies presented here leave little doubt that DDR&E played a very active role in many program decisions in the 1970s, and, in most cases, the interventions described clearly seem beneficial. But they do not give a clear picture of DDR&E's effectiveness in improving acquisition overall.

One partial but useful way to survey effectiveness is to look at cost growth. Aside from its intrinsic importance, cost growth is closely associated with many other program problems and thus serves as a meaningful indication of trouble. Out of several hundred significant individual programs that were the subject of DDR&E attention during the decade, cost data are available on forty, with comparable data from comparable numbers of programs in the following two decades. The data sets have been constructed, under Cost Analysis Improvement Group (CAIG) sponsorship, from a careful analysis of the data recorded in Selected Acquisition Reports covering Major Defense Acquisition Programs. They reflect the growth in cost (in constant dollars and adjusted for quantity changes) over the targets approved at the time of Milestone II, which marks their official inauguration as a program. In this analysis the figures have been adjusted to remove the effects of changes in requirements as well as the effects of external budget direction. Thus they reflect, as nearly as possible, the strength or weakness of the original program concept and its subsequent management.

Cost growth is common in acquisition programs but it varies a good deal in amount, and even in sign, being negative in a few cases. There were programs with high cost growth in the 1970s, just as there were in the 1980s and 1990s (and it is already clear that some 2000s programs also have high cost growth, even though the full extent is not yet certain). But on the whole the cost growth experience of late 1970s programs was superior to that of the later eras, as shown in Figure 16. Programs that had their inception between 1976 and 1980, shown by the solid purple line, in general had lower growth that those from earlier or later periods. It is possible that the differences between the results from 1976 to 1980 and other periods are merely chance, but statistical tests show that this is unlikely to highly unlikely.[196]

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[196] For details see Appendix A.

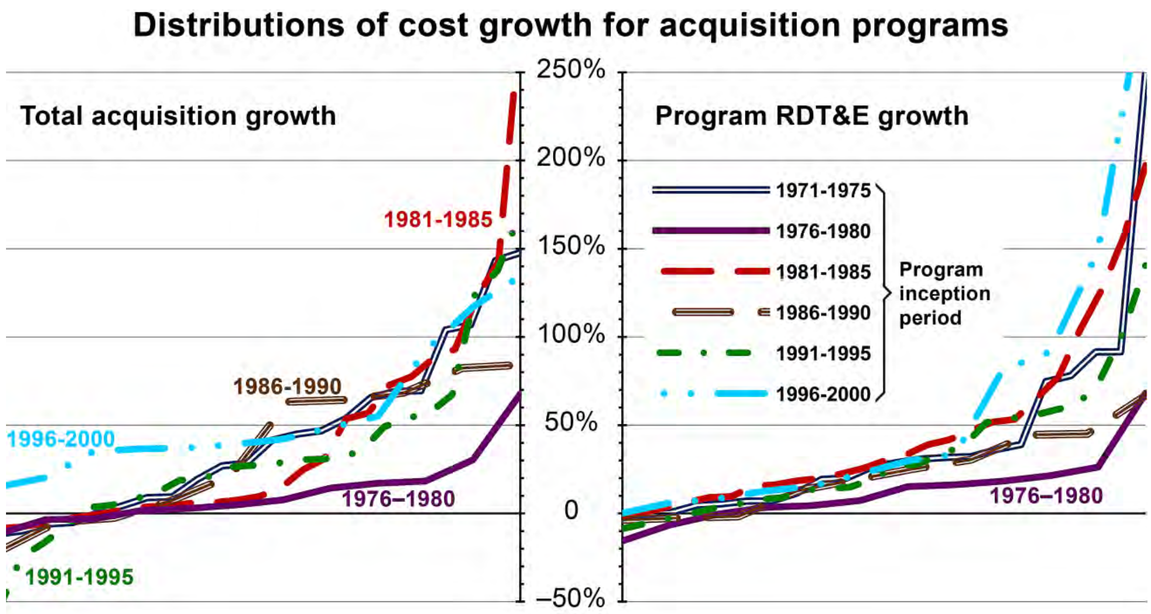

Figure 16. Distributions of MDAP Cost Growth by Semidecade of Program Inception

This does not tell us how much of the difference is due to DDR&E, but clearly the organization did play a central role in the 1970s (particularly in R&D) and it is hard to identify another factor that changed as greatly after the 1979s. Thus is it reasonable to attribute much, if not all, of the superior performance between 1976 and 1980 to DDR&E's efforts. DDR&E did not always have the power to do as it wanted nor the wisdom to want what was truly best, but on the whole it was a real force for the better and the nation lost something when it was weakened.

Another rough measure of program success is the longevity of the product. Four-fifths of the systems that had their inception in the 1970s remain in first-line service three to four decades later, comparable to the rate for the more recent 1980s systems.

B. The Primary Lessons

1. The Front-end Technology-Operations Interface

The fundamental distinction between DDR&E and the much less effective earlier mechanisms for directing DOD R&D programs was that DDR&E had and used the power to intervene early, powerfully, and decisively to determine when and how technology could be used to meet defense needs. This was not accidental or incidental. It was exactly what President Eisenhower had called for in his message to Congress on 3 April 1958 that had led to the original establishment of DDR&E.

As the story of the high Reynolds Number wind tunnel illustrates, DDR&E played a major role in setting DOD's (and the nation's) technology agenda. But from the perspective of this study, with its emphasis on decisions about what to buy, it is important to recognize DDR&E's distinctive and powerful role at the interface between technology and military operations.

The case of the ROTHR is a good example. DDR&E was not responsible for the development of OTHR technology, but DDR&E staff members were the ones who saw how it could play a central role in a new approach to strengthening air defense for forces at sea, and at land facilities in maritime areas, and who pushed this recognition through to effective realization. Without a given preexisting "military requirement," or even a maritime area air defense mission – DDR&E (and its USDRE successor) recognized that there was a need that could be met and acted to fill it. The same thing is seen, with variations, throughout the history not only of DDR&E but of its World War II predecessor, OSRD. Even when the issue was technology per se, DDR&E focused on what might be operationally significant in the future.

Getting these decisions right was far from trivial, because it required a fairly precise and accurate assessment of what the technology could ultimately deliver, what the resource implications were likely to be, and how much operational difference a given level of capability would make. DDR&E's record in these matters was certainly not perfect, but on the whole it was remarkably good. The greatest shortfalls tended to be in the underestimation of resource requirements.

The obverse of DDR&E's initiative was its role in redirecting, regulating, and sometimes squelching programs advocated by the Services. As detailed studies of specific acquisition programs have shown, both the problems and potential of a program are very largely fixed by the adoption of the initial technical and development concept.[197] Because DDR&E was well qualified and positioned to recognize both the technical and operational implications (often with the aid of PA&E) it could and often did exercise a very beneficial influence on outcomes.

Missile Defense Alarm System/Defense Support Program (MIDAS/DSP) offers a good example of how much DDR&E could do to improve a program based on its understanding of the intersection of technology and operational need. When circumstances or incapacity effectively blocked DDR&E's early intervention, the results could be costly in terms not only of money but lost capability, as the examples of the SES and F-111 indicate.

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[197] Gene Porter et al., *The Major Causes of Cost Growth in Defense Acquisition*, P-4531 (Alexandria, VA: Institute for Defense Analyses, Dec 2009).

2. Intervention Can Be Far More Effective in the Early Stages

System concepts generally hardened at a very early stage, and gained a consensus of support that quickly grew so strong that change became a struggle, even when it was clearly important. The supreme example is the TFX/F-111, which seemed to have sprung from the mind of the SECDEF and, thereafter, became all but unalterable. The only point at which DDR&E might have been able to intervene without major upheaval was in February 1961, which was, unfortunately, during the interregnum after York had left and Brown had yet to be confirmed.

More mundane cases carry the same fundamental message. As was shown in the Surface Effect Ship case, there was the potential for a moderately successful program rather than a dismal failure, but the window for exerting a positive effect closed very early.

In the case of surveillance for forward area maritime air defense, early efforts by the DDR&E and PA&E staffs led to a variety of improvements in the Navy's concepts and program structure. In the end, it was the DDR&E staff's alternative, the ROTHR, that won out, because DDR&E was able to bring it forward before strong support had coalesced behind the SBR favored by a key component of the Navy staff. Indeed, the whole issue had been decided before the ITSS program ever got to the equivalent of a Matériel Development Decision (MDD). As a result, there was minimal waste of resources and modest delay in moving ahead on the ROTHR.

3. The Importance of DDR&E's Heritage

DDR&E was not simply one more bureaucratic office; it was an institution with a heritage that contributed to its success. The heritage drew on the prestige of science and technology in American society, but it originated more directly in the success of OSRD in World War II and the heroic stature it achieved. OSRD had served as a co-equal rather than a subordinate to the military and thus established the independent status of S&T.

This independence was somewhat undercut by the military's takeover of the direction of the atomic bomb program (at the insistence of Vannevar Bush), suggesting that civilians were not able to manage major projects on their own. But post-war weapons development fell under civilian control at the top with very good results. And it took the appointment of a civilian "missile czar" to untangle the missile programs.

Thus when Sputnik created a climate that was receptive, President Eisenhower was able (with difficulty, to be sure) to persuade Congress to establish DDR&E as an organization with a mandate for real power over acquisition. As engineer-scientist-managers drawn from the prestigious and successful civilian nuclear weapons establishment, its early directors were able to elevate DDR&E's status and to use a heroic heritage that legitimatized and reinforced its power. In essence, they were able to set its heritage as a counterbalance to those of the Services.

This prestige brought important advantages, particularly in relations with Congress and the Services. Although both had frequently denigrated the competence and knowledge of OSD staff as a way of undercutting SECDEF authority, they were discernibly less prone to do so with DDR&E. And, in direct correlation, Congress was not very prone to overrule DDR&E, or to yield to Service pleas to do so.

But DDR&E's prestige was a fragile asset, easily tarnished. We can see this in connection with the F-111, where DDR&E made some errors of judgment and got rather roughly handled by Congress. It was important for DDR&E to be right in order to preserve its credibility.

4. An Elite Staff

The men who served as DDR&E all showed that they understood very clearly that to uphold the elite status of their organization they needed an elite staff to support them and execute their will. They utilized the high prestige of DDR&E to attract top quality personnel, but also secured a very generous allotment of P.L.313 billets (equivalent to today's Senior Executive Service grades) to ensure material incentives (although many staff members took pay cuts to move from industry jobs to DDR&E). And they did not hesitate to make use of personnel rules to get rid of staff members whom they believed were not measuring up. They also substantially reduced the military presence on the staff and eliminated military officers from top-level positions, out of concern for the unavoidable conflicts of interest officers often faced.

Staff members had engineering or scientific educations and more or less extended engineering experience in industry and/or in government technical organizations. Staff members dealing with acquisition programs were expected to understand all of the program's technical aspects and how they interrelated and integrated at the system level to affect performance and cost. Those responsible for S&T issues, as well as those who addressed advanced technology programs, needed to understand the underlying technology strategy and prospects. They needed to be able to explain these matters very clearly and succinctly to those whose own understanding was less detailed but very deeply rooted. And they also needed to be able to discuss them and their implications in terms that would be clear and convincing to officers and officials who had less technical background, often much less.

Beyond that, staff members needed to have or quickly develop a thorough grasp of the Planning, Programming, and Budgeting System (PPBS), budget execution, Congressional relations, the military requirements process, and the Service chains of command as they applied to technology and acquisition programs. Finally, a good understanding of the military operational setting relevant to the programs involved was crucial.

The result was quality advice and efforts to ensure execution of DDR&E decisions and desires. The staff also exercised a great deal of independent initiative, but in ways that were consistent with top-level priorities and guidance. Occasionally a staff member was rebuked for crossing the line, but this was rare. At the same time, the staff was expected to act vigorously to shield DDR&E from needless and unproductive conflict or controversy.

The staff was not always first rate in every area, and the thin spots could be quite troublesome. Lack of staff personnel who knew enough about tactical aircraft was costly in the case of the F-111, for example. But by the 1970s DDR&E had built a staff with good knowledge of all the technology areas of potential military significance, and all the major operational applications of technology.

5. Bias, Objectivity, and Innovation

It is well known that cost growth has been a significant acquisition issue for many years. There is some tendency to downplay the significance of cost growth per se, but as one-time DEPSECDEF David Packard trenchantly observed long ago, cost growth is a product of various acquisition mistakes, and thus it can serve as convenient index of them.[198] While the majority of acquisition programs come reasonably close to meeting their cost and other goals (considering the inherent uncertainties and risks that they involve) roughly a quarter show notably high levels of cost growth. Every new administration in the Pentagon for the past half century has launched initiatives to reduce cost growth, but as shown in Figure 16 the problem, at least since the 1970s, has not gotten materially better.[199]

Social and management scientists have identified similar phenomena in a wide range of non-defense development and production activities as well, and have ascribed this to a disynergistic interaction of the universal psychological tendencies known as the planning fallacy and optimism bias with the operation of perverse incentives that asymmetrically reward excessive optimism. The evidence to date suggests that the best way to counteract flawed plans is to provide decision makers with predictions derived

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[198] David Packard, "Address by the Honorable David Packard, Deputy Secretary of Defense at Armed Forces Management Association Dinner, International Hotel, Los Angeles, Calif., Thursday, August 20, 1970," *Defense Management Journal* 6 (Summer 1970): 60-63, (See Appendix D).

[199] David L. McNicol, *Cost Growth in Major Weapon Procurement Programs*, Second Edition, P-3832 (Alexandria, VA: Institute for Defense Analyses, 2005); Gene Porter et al., *The Major Causes of Cost Growth in Defense Acquisition*, P-4531 (Alexandria, VA: Institute for Defense Analyses, Dec 2009). This assessment of course excepts the current administration, since cost growth generally does not become manifest for several years and it is thus far too early to evaluate its initiatives.

from analysis of earlier comparable projects by experts who have incentives against overoptimism.[200] Clearly, the independent cost estimates made by the Cost Analysis Improvement Group fall into this category. Analyses of CAIG estimates of production costs, however, demonstrate that they also tend to show some optimistic bias – and underestimates are generally greater for development costs.[201] Case studies have suggested that inaccurate information about the system risks and characteristics of a new program can be one major source of inaccuracy in CAIG cost estimates.[202]

Aside from the effects on estimates of resource requirements, an inadequate understanding of system risks and characteristics can lead to optimistic estimates of military potential, schedule, support needs, environmental impacts, and economic benefits. Similar problems are documented for non-military programs and for complex projects in private industry as well.[203]

In its evaluation of Service programs in the 1970s, DDR&E served as a technically competent oversight organization incentivized to assess programs accurately rather than to be optimistic or pessimistic. Although there almost certainly were pressures for optimism, and some much more limited pressures for pessimism, at least in the 1970s the expectation of the top officials at DOD was that DDR&E get it right, and for the most part this expectation dominated.

Clearly this was not always the case. In 1961 the fact that the F-111 program was warmly embraced by the SECDEF unquestionably made objectivity much harder, and no doubt contributed to DDR&E's stumbles. We have found nothing to suggest that people in DDR&E supported the program out of cynical self-interest. Rather, the evidence indicates that the SECDEF's advocacy simply validated their normal human tendencies for optimism bias and allowed the planning fallacy to come to the surface. With some limited exceptions, however, the top officials in DOD steered clear of acquisition

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200 Bent Flyvbjerg, "Curbing Optimism Bias and Strategic Misrepresentation in Planning: Reference Class Forecasting in Practice," *European Planning Studies* 16, no. 1 (Jan 2008): 3-21; Bent Flyvbjerg, Massimo Garbuio, and Dan Lovallo, "Delusion and Deception in Large Infrastructure Projects: Two Models for Explaining and Preventing Executive Disaster," *California Management Review* 51, no. 2 (Winter 2009): 170-93; Bent Flyvbjerg, "Survival of the Unfittest: Why the Worst Infrastructure Gets Built—And What We Can Do About it," *Oxford Review of Economic Policy* 25, no. 3 (2009): 344-67; Buehler, Griffin, and Peetz, "The Planning Fallacy: Cognitive, Motivational, and Social Origins."

201 David L. McNicol et al., "The Accuracy of Independent Estimates of the Procurement Costs of Major Systems," P-3989 (Alexandria, VA: Institute for Defense Analyses, August 2006).

202 Porter et al., *The Major Causes of Cost Growth in Defense Acquisition.*

203 Dan Lovallo and Daniel Kahneman, "Delusions of Success: How Optimism Undermines Executives' Decisions," *Harvard Business Review* 81, no. 7 (July 2003): 29-36; Edward W. Merrow, Kenneth E. Phillips, and Christopher W. Myers, *Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants*, R-2569-DOE (Santa Monica, CA: RAND Corp., 1981).

program advocacy in the 1970s and those who served as DDR&E inculcated a culture of objectivity.

In assessing Service proposals the DDR&E staff made frequent use of analytical comparisons with other systems that were similar in some characteristic. This can be seen, for instance, in some of the staff papers on the SES program that are reproduced in Appendix D. This methodology has been widely used in engineering for at least 250 years, and is, conceptually, comparable to the methods the CAIG uses for cost analysis.[204] They conform to the recommendations offered by social and management scientists for debiasing projections of performance, schedule, and cost.[205] In addition, the staff regularly consulted other knowledgeable people, both within DDR&E and outside, to gain broader information and perspective.

As we have observed, in pursuing the mandate for innovation there were some cases when DDR&E personnel actually functioned as advocates or even initiators of programs. In the 1960s, DDR&E advocated the F-111 digital avionics suite, which was definitely oversold in terms of schedule and cost. Although we have no direct proof, we can conclude that lack of objectivity contributed to the mistakes in DDR&E assessment.

In the 1970s, however, we have not found evidence of unwonted optimism in connection with programs advocated by DDR&E or members of the staff. This could of course be simply the result of lack of sufficient evidence, but in the ROTHR case, which is better documented, we see no significant over-optimism. The larger predictions regarding overall ROTHR operational effectiveness were never put to the test due to the end of the Cold War, but the results of the development were broadly compatible with the predictions advanced by the DDR&E staff in terms of system performance, cost, and schedule.

This outcome is understandable in light of the culture of objectivity supported by the leadership. Both Perry and DeLauer, the two leaders whose tenures spanned the ROTHR effort, were interested and supportive, but did not become active advocates. They gave no signals that would conflict with their standards of objectivity. Thus the staff members who were advocates of the ROTHR felt no authoritative reinforcement for any tendencies toward the planning fallacy or optimism bias, and remained aware of the organization's cultural norm of objectivity.

Human motivations are far too complex and diverse to be reduced to a simple univariate formula, but the cultural norm of objectivity fostered by the top OSD and

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[204] Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies From Aeronautical History* (Baltimore: Johns Hopkins University Press, 1990), 138-40.

[205] Bent Flyvbjerg, "Curbing Optimism Bias and Strategic Misrepresentation in Planning: Reference Class Forecasting in Practice," *European Planning Studies* 16, no. 1 (Jan 2008): 3-21.

DDR&E leadership appears to have operated powerfully in the DDR&E of the 1970s. Although the DDR&E leadership did advocate innovation and technological progress in general, this does not appear to have operated to significantly foster excessive optimism.

6. Communications, Unity of Action, and Staff Size

In the 1970s, communication within DDR&E was excellent. Virtually everyone on the staff knew each other and felt a close sense of connection with the DDR&E himself. It was an atmosphere somewhat like that of Admiral Horatio Nelson's famous "band of brothers."[206] Following the transition to the USDRE organization in 1977, the staff noted a marked deterioration in inter-group communication and unity of action. While differences in leadership style may have played a part in the change, as they surely did in the difference between Nelson's results and those of other contemporary commanders, there are good reasons to see it as mostly influenced by the increased staff size.

A better analogy than war for what DDR&E was involved in may be entrepreneurship. While it has long been observed that small firms can be more entrepreneurial than large ones, it is now becoming clearer that this is related to relatively immutable biological factors.

Anthropologists have argued for many decades that inherent limits on the human capacity for intimate relationships constrain the potential effectiveness and efficiency of groups beyond certain relatively small limits in size.[207] More recently, evolutionary anthropologists and scientists in related fields have found a significant amount of evidence that the neocortex is the seat of group forming in the brain and that it is the size of the neocortex that imposes limits on the formation and functioning of groups among humans and indeed among many animals.[208]

This brings with it the strong tendency of humans and our primate relatives to have a nested hierarchy of association groups, with an inverse relationship between the size of a group within the hierarchy and the degree of intimacy with its members. The index to this hierarchy is Dunbar's Number, the cognitive outer limit on the number of individuals with which it is possible to maintain intimate relationships at any one time. Its value in

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206 This was the Shakespearian sobriquet Nelson applied to the captains whom he formed into a single-minded close-knit group before the Battle of the Nile in 1798. See Andrew Lambert, "Nelson's band of brothers (*act.* 1798)," *Oxford Dictionary of National Biography*, Oxford University Press, Sept 2010. http://www.oxforddnb.com/view/theme/96379.

207 Carleton S. Coon, "The Universality of Natural Groupings in Human Societies," *Journal of Educational Sociology* 20, No. 3 (Nov 1946): 163-168.

208 R.I.M. Dunbar and Suzanne Shultz, "Evolution in the Social Brain," *Science* 317 (27 Sep 2007): 1344-47; Suzanne Shultz and R.I.M. Dunbar, "The Evolution of the Social Brain: Anthropoid Primates Contrast With Other Vertebrates," *Proceedings of the Royal Society B* 274 (2007): 2429-36; Idem, "Understanding Primate Brain Evolution," *Proceedings of the Royal Society B* 272 (2007): 649-58.

humans has been estimated on a number of bases, converging to an average of approximately 150.[209]

Based on data from economics as well as anthropology, a model of the relationship between entrepreneurial innovation and group size has been constructed which indicates that there is a fairly distinct change which occurs as the size of the business unit reaches some critical cognitive limit which is a function both of group interaction and the efficacy of the leadership. Above this limit, internal cooperation diminishes as group members become more influenced by the members of their own clique and individual conceptions of self-interest than by the leader's vision. As the size exceeds the biological limit on the number of intimate relationships even the strongest leader can no longer impose a central cooperative vision effectively and a much more anarchic group dynamic takes over, leading relatively quickly to an anomic bureaucracy, with baleful implications for organizational effectiveness.[210]

This appears to be the lesson of the 1977 change. We have no direct way to compare the leadership capacity of Currie in 1976 with that of Perry in the following years, but Perry's history as a successful military officer and entrepreneur certainly gives reason to expect that he was an effective leader. Thus the decline in communication and cooperation among the staff and in the organization's capacity for swift and decisive action (outside of a limited number of high-interest areas) during his tenure probably was largely a function of the increased staff size associated with the transition from DDR&E to USDRE.

Prior to 1977, DDR&Es rarely seemed to have any difficulty in quickly identifying and reaching out directly to the staff member(s) who could best help on a particular issue. Conversely, individual staff members generally were able to bring their concerns to the attention of the DDR&E, although the speed and efficiency of these upward communications did vary somewhat based on the individuals at the intervening levels. Again, the numbers were small enough that close connections could always be made in one step or at most two.

Incoming members of the staff were instructed to work closely and effectively with their counterparts elsewhere and occasional lapses in this regard evoked management notice and correction. Relationships with PA&E (Systems Analysis) and the Comptroller tended to be especially constant and important, but many others from other OSD offices,

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[209] R.A. Hill and R.I.M. Dunbar, "Social Network Size in Humans," *Human Nature* 14, no. 1 (Mar 2003): 53-77; W.-X. Zhou et al., "Discrete Hierarchical Organization of Social Group Sizes," *Proceedings of the Royal Society B* 272 (2005): 439-44.

[210] Christian Cordes, Peter J. Richerson, and Georg Schwesinger, "How Corporate Cultures Coevolve with the Business Environment: The Case of Firm Growth Crises and Industry Evolution" (*Journal of Economic Behavior and Organization*, in press 2010).

the Joint Staff, and the Services might be involved as the occasion warranted. The integrated product team did not exist as a formal concept, but IPTs most certainly did in practice. However, they were notably fluid, with the composition shifting dynamically as the nature of issues and decisions dictated. The result was that the staff members could exert powerful external influence as part of the team, particularly in PPBS matters, as well as in coordinating action on acquisition program decisions.

When the organization expanded in 1977-1978 to become USDRE, internal communications degraded and staff members felt more out of touch with the leadership. This reduced the level of integration within the organization and it became less capable of swift and decisive action outside of a limited number of high-interest areas.

In addition to the breadth of technical and operational knowledge demanded by the small size of the staff, good internal cooperation depended on the staff's skills in oral and written communication. Many good engineers lack innate facility in communications and have not worked to develop their skills, which further limited the potential pool for staff recruitment.

7. Focus

The tradeoff of the small staff was that each member needed to have the ability to understand a broad range of technical and operational issues. This need was met with good success. But even so there were limits to how deeply the staff could go into the multitude of potential issues.

This appears to have been a deliberate choice. The sparse data we have suggests that the DDR&E staff had been substantially larger in the mid-1960s than it was in the 1970s, and remarks made by Foster indicate that the staff was cut back with the intention of improving quality and focus.

There are risks to such a strategy. An unattended problem can occasion sharp criticism even though its real military or economic importance is relatively small, or, indeed, even if it is purely symbolic or nominal in nature. And minor problems left unattended can sometimes turn malignant. The leaders of the organization were not unaware of this occurring, but they expressed the belief that the attempt to foresee and control every possible problem was foredoomed, and that it could only divert attention and resources from the most significant issues. They believed that so long as they got the big things right, minor problems could be dealt with as they emerged, and, in fact, this strategy worked well for them. The DDR&E leadership also sought to understand the time constants associated with the various processes and sub-processes they were dealing with and to adjust the frequency with which these issues were revisited in light of the time it might be expected to take for a perturbation to grow to significant size.

8. DDR&E is Always Subject to Administration Policy

While the effectiveness of DDR&E in executing the SECDEF's policies and desires varied, it always had to operate within their limits. Through much of the 1960s McNamara had definite ideas about what should be developed and produced, and DDR&E strove to carry them out. Its mixed success reflected the organization's own limitations to some extent, but also the problems inherent in some of the basic concepts.

In the 1970s the DOD administrations generally gave DDR&E permission and encouragement to take a more independent and active role in fostering effective technological innovation and improving program execution processes, with limited specific direction. DDR&E on the whole rose to this challenge well, but this top-level policy played a crucial facilitative role in its success.

Although the move to the larger and less agile USDRE structure in 1977 appears to have limited the effectiveness of the organization in fostering innovation and guiding decisions on what was to be bought, it was the change in top-level policy in 1981 that had the most decisive effect. In the 1970s the DOD administrations supported or were at least receptive to a strong DDR&E/USDRE role. But in the 1980s DOD wanted the military departments to assume the lead and called for USDRE to take a passive role in these areas, preferring that it concentrate instead on technical improvements in procedural and managerial practice. Complaints that virtues in procedures or management could not compensate for defects built into the initial concept were not persuasive to top officials convinced that the Services were best qualified to formulate concepts based on their understanding of their needs. In a way, this trust that the Services were uniquely qualified to formulate concepts based on their understanding of their needs bespoke the trust of these top officials in the power and mutability of technology, but it was too often trust misplaced.

C. Recommendations

A great deal has changed since the end of the first DDR&E era. From their lows at the end of the Ford Administration in FY 1976, procurement spending has grown by more than 120 percent while spending for RDT&E has increased by more than 150 percent, in real terms.[211] The size of the DDR&E staff has increased very substantially, while many of its former functions are now the responsibility of other offices in the much larger AT&L organization.

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[211] Office of the Secretary of Defense (Comptroller), *National Defense Budget Estimates for FY 2011*, Mar 2010, (the "Green Book"), Table 6-11.

The growth in severely troubled acquisition programs has outpaced even these measures of increased complexity.[212] The Weapon System Acquisition Reform Act of 2009 (WSARA 2009) has called for a variety of reforms, including strengthening the Department's key development planning function under the Director, Systems Engineering, who now reports to the DDR&E. While this can do little to resolve the problems of acquisitions that saw their inceptions in the 1990s and 2000s, it is critical to future improvement.

A principal goal of this research was to identify attributes of the successful DDR&E of the 1970s that could be effectively applied within the current structure and procedures of the Department to improve the process for starting and developing new weapon system acquisition programs. The new provisions of WSARA 2009, including strengthening the Development Planning function, imply the requirement and opportunity to apply several key lessons. Accordingly, we offer the following recommendations. The first three are key recommendations, while the remaining recommendations support these first three.

1. Key Recommendation 1: Involvement at the Earliest Possible Stage

Ensure that personnel experienced in system design and operations analysis, and free of bias and conflicts of interest, are directly and substantively involved in and approve of the early concept formulation and requirements determinations for all new major weapon systems, prior to formal Defense Acquisition Executive approval of a new program start at the MDD point.

2. Key Recommendation 2: Active Role in Innovation

Increase the authority of DDR&E to initiate and guide promising new and innovative technological approaches, including Advanced Capability Technology Demonstrations that can lead to important new military capabilities, as well as attract highly qualified scientists and engineers to government service.

3. Key Recommendation 3: Development Planning

Empower DDR&E to review and approve the adequacy of every development plan and associated funding profile as a condition for starting any new major acquisition program.

The following recommendations are actions to support the key recommendations:

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[212] Gene Porter et al., *The Major Causes of Cost Growth in Defense Acquisition*, P-4531 (Alexandria, VA: Institute for Defense Analyses, Dec 2009).

4. Supporting Recommendation 4: Position DDR&E at the Technology-Operations Interface

The history shows that the unique contribution of engineers and applied scientists in defense management comes at the interface between the available and the desirable, between what technologies can best provide and what operations can gain most from them. Inherently, military officers tend to envision technology as a servant that must meet their needs as they define them, but this approach leads repeatedly and predictably to flawed developments on the one hand and the failure to realize the true potential of technology on the other. If the nation is to get the fullest defense benefit from technology, it is essential that the technologists take a full and active share in formulating the fundamental ideas and specifications for its application.

The importance of this is greater still because so much of the potential of programs, for good or ill, is fixed by their initial concept. If the initial concept is deficient, either in technical or military terms, then the risk that the program will have bad results is correspondingly increased.

This responsibility is shared within OSD with the Cost Analysis and Program Evaluation (CAPE) directorate (as the successor to PA&E is now known). CAPE's major focus on resource and force structure implications is complementary to the issues of the technical prospects for prospective systems and their implications for employment and effectiveness that are the natural strengths of DDR&E. Moreover, the accurate and objective technical information that DDR&E can supply using comparative engineering analysis at an early stage can significantly improve CAPE's resource and force structure analyses.

DDR&E's potential to provide good technical estimates at the outset and to make it possible for CAPE to provide good early resource estimates is of supreme importance for improving acquisition. Case studies consistently demonstrate that most of the problems and limitations of systems are genetic defects, determined at the program's conception. Attempts to transcend the built-in limitations of the fundamental concept are inevitably fraught and expensive, but mismatches between stated requirements and the concept's actual potential regularly give rise to them. If the implications are understood clearly and accurately at the beginning then either a search can be initiated for a concept better able to fulfill the desired characteristics or the expectations can be adjusted to reflect the reality. No other organization is better positioned or more qualified to do this than DDR&E.

5. Supporting Recommendation 5: Make Use of DDR&E's Heritage

Heritage does not usually figure into the calculations of engineers and they can be prone to dismiss its importance, but a heritage like DDR&E's is a real and tangible asset.

First, it serves as a summary record of accomplishment and an indication of what can reasonably be expected. And, second, it inspires and unifies the staff.

It should be remembered that the organization's heritage actually begins with the creation of OSRD in 1940, not just the formal establishment of DDR&E in 1959. And it includes President Eisenhower's strong and clear statement of its mission in his 1958 message to Congress.

The central message of this heritage is that engineers and applied scientists working at the interface between technology and military operational needs have a crucial part to play in intelligently choosing whether and how technology can best be applied to meet a need.

"Reputation of power is power," as Hobbes said.[213] Those who lack sufficient specific knowledge and the time or means to acquire it must judge the capacity of individuals and organizations largely on the basis of reputation, which is to say, on the basis of their history. DDR&E owes it to those it serves to deepen and clarify its reputation by reminding them forcefully of its heritage.

6. Supporting Recommendation 6: Continuously Improve Staff Quality

The point of this is not to suggest that the present staff is inadequate but that improvement is an ongoing process. Just as in manufacturing, a program of continuous improvement is needed to prevent quality from eroding.

Beyond the fundamental intellectual qualities of the staff, particular knowledge and skills are needed, including:

- Communication skills, both in writing and presentation. These can be developed through training and practice, but there must be a foundation of basic capacity as well as a willingness to devote work to subjects that do not come naturally to many who have chosen engineering as a profession.
- Broad technical knowledge and the basic scientific grounding to permit rapid understanding of the fundamentals of a new technical field. And this needs to be coupled with a facility in shifting from one subject to another in order to be able to cover a wide range of programs and adapt as new needs arise. The person whose natural forte is deep involvement in a single subject is likely to be too inflexible.
- Understanding of military operations. Needless to say, this is not common among engineers and a deliberate effort to develop it is necessary. While reading

[213] Thomas Hobbes, *Leviathan, or The Matter, Forme and Power of a Common Wealth Ecclesiasticall and Civil* (London: Andrew Crooke, 1651), chapter X.

and/or instruction can be useful in many respects, it is difficult to gain adequate understanding of the relevant issues in this way alone. DDR&E should actively work to get its personnel out into the field with the Services to observe operations first hand and speak to Service personnel about what they do, for periods of a few days to a few weeks at a time. Participation in training oriented war games also can be valuable. Personnel should also be encouraged to read about military operations, and a recommended reading list and lending library should be established and kept up to date.

- Understanding of the essentials of the Joint Capabilities Integration and Development System, the PPBS, the acquisition process, the Federal Acquisition Regulations and the Defense Federal Acquisition Regulation Supplement, and defense economics. This understanding is necessary to communicate and coordinate effectively with the various organizations that DDR&E must work with for real effectiveness.
- Understanding of the business operations and incentives acting upon defense contractors.
- Understanding of the findings of social psychology, management science, behavioral economics, and related disciplines that are most relevant to requirements and acquisition, including optimism bias, the planning fallacy, and intragroup dynamics.

No one is going to be a thorough master of all these subjects, but major deficiencies in any of these areas are bound to have significantly adverse effects on DDR&E's performance. DDR&E can and should have an ongoing, active program to improve the quality of its staff in all of these areas.

It might at first seem that assigning technically qualified military officers to DDR&E would do much to fill the need for knowledge of military operations, but such an arrangement must be approached with considerable caution because the DDR&E staff cannot function adequately if its members feel constrained or even strongly motivated to support Service positions. (It is also the case that military officers with the strong technical qualifications needed in DDR&E often have quite limited knowledge of operations.) Employment of former military personnel (officer or enlisted) or engineers who are active in the reserves may be useful, however.

7. Supporting Recommendation 7: Promote Objectivity, Innovation, and Close Communication

Nothing is more fundamental to DDR&E than innovation; it is the original reason for the organization's existence and management must ensure that no one ever loses sight of it. Attempts to direct innovation from the top down invariably grow stagnant and sterile; the staff must be encouraged to contribute actively and creatively.

In order to promote the DDR&E's goals effectively there must be close coordination with and among the staff, who in turn must work closely and effectively with others to communicate the organization's goals and direction. This depends to a large degree upon the DDR&E's own powers of clear and effective communication, but no amount of top leadership can overcome the dissipative forces in an organization that grows beyond a critical threshold that is on the order of 150 individuals. If a larger organization truly is necessary to meet assigned responsibilities, special study should be devoted to mechanisms to compensate as far as possible. It should not be assumed that a larger staff can be led and coordinated by the same means as a smaller one.

So long as staff members are acting to carry out the vision set by the DDR&E they must be supported. It is particularly essential that the DDR&E support and shield staff members who are attacked for their efforts by those whose real aim is to curtail DDR&E power and authority.

In order to effectively foster innovation it is important that DDR&E be and appear to be impartial and objective in its assessments of proposed programs, whatever the origin of the initiative. Beyond the attitude of the leadership, the principal practical technique for promoting unbiased and objective assessment is comparative analysis. Advocates often object on the grounds that the innovation is so unique as to defy meaningful comparative analysis, but unless the technology is extremely immature, this very rarely turns out to be true.

8. Supporting Recommendation 8: Institutionalize Learning from Experience

No matter how focused the organization is on the future, there is always a great deal to be learned from an analysis of experience. The strongest basis for getting better results in the future is to examine past performance and identify the reasons for its successes and failures. Thus DDR&E should keep records detailing the course of information and action on programs and use them to conduct critical after-action reviews so that the organization's performance can be continuously assessed and improved.

Appendix A
Statistics of Cost Growth

This paper has benefitted from access to a cost growth data set generously provided by the Cost Analysis Improvement Group (CAIG). Although the data were taken from Selected Acquisition Reports (SARs), the raw SAR data, as presented, suffer from a variety of problems as sources of information on cost growth.[1] Thus, under CAIG sponsorship the data have been refined, corrected, and categorized to more clearly indicate the specific causes of individual items of cost growth. Although many important acquisition and research and development (R&D) programs were never reported in SARs, and therefore do not appear in the database, this is, as far as we know, the most complete and comprehensive set of data available.

The categorizations were used to exclude cost growth arising from causes that the Director of Defense Research and Engineering (DDR&E) would have been unlikely to have foreseen or affected, including major requirements changes and external budget actions. Also excluded were most ship programs, which normally had no significant development effort (as opposed to design) and were managed by systems that DDR&E had little ability to affect. A few programs, which had no R&D effort because they were new production batches of systems already developed or of commercially-developed systems, were also excluded.

It was also necessary to give the C-130J program special treatment. It was originally a contractor initiative, planned as a fairly straightforward upgrade of a design that had been in production for decades, with little Research, Development, Test, and Evaluation (RDT&E) envisioned. In reality it turned out to be considerably more complex than originally envisioned and the development cost grew a great deal. One specific issue resulted in the enormous percentage growth in development cost, nearly 2400 percent; it was belatedly recognized that no provision had been made in the plans to meet the policy requiring Global Air Traffic Management (GATM). In the plots included below this source of extreme cost growth has not been shown in order to avoid excessively distorting the values. So the growth in cost of the C-130J program has been shown without the inclusion of GATM.

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[1] Paul G. Hough, *Pitfalls in Calculating Cost Growth From Selected Acquisition Reports*, N-3136-AF (Santa Monica, CA: RAND Corp., 1992).

Plots of the resulting time series are displayed in as Figure A-1. Because the peak of DDR&E influence typically came near Milestone I, growth from that point is particularly interesting. Unfortunately, since only a minority of programs has received formal cost estimates at Milestone I, resulting in quite a small sample, it would be rash to draw any sweeping conclusions on this basis. Milestone II data, on the other hand, provides a much denser sample.

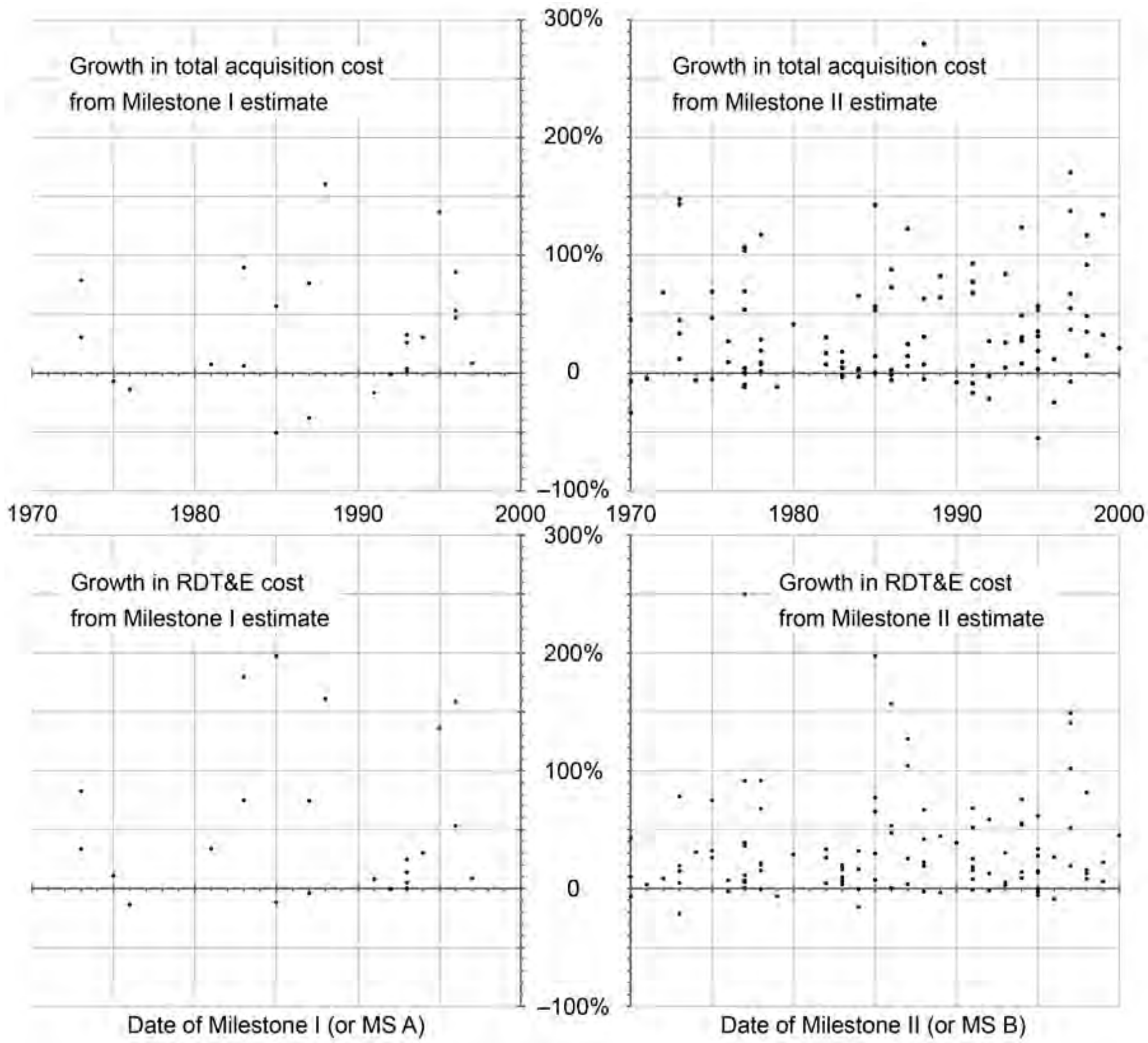

Figure A-1. Time Series Plots

It seems clear from these plots that if we examine the distribution of growth points in each individual epoch in the series it will be strongly non-Gaussian and skewed, with a much-extended right-hand tail. Statistical tests confirm that it is extremely unlikely that these data represent a sample from a normal distribution.

The plots of Figure A-1 appear to hint of some trend over time. Linear trends have been estimated using ordinary least squares regression, with results presented in Figure

A-2. Because the major DDR&E influence came very early in a program's life the independent variable here is taken as the date of inception, defined as the date of Milestone I, or if there is none, then two years before Milestone II.

The slopes of the regression model lines, i.e., the long-term average rates at which cost growth increases over this period, are 4.4 percent per decade for total acquisition cost growth and 7.3 percent per decade for RDT&E cost growth. The R^2 values, the proportions of total variation explained by the secular trend, are only 0.006 and 0.016, respectively. The regressions were estimated without the C-130J outlier; its inclusion would make the R^2 values seem smaller still.

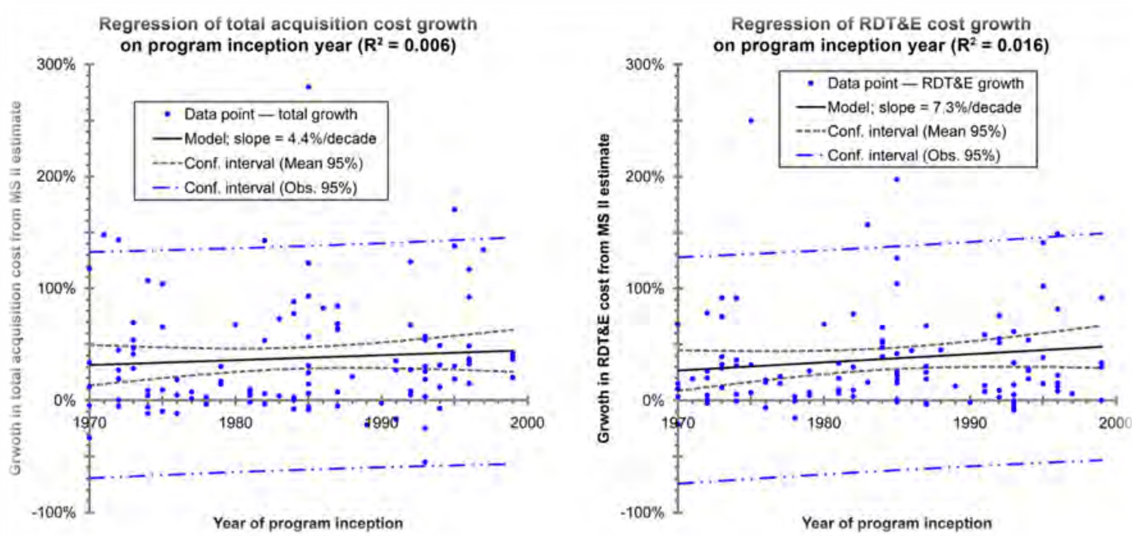

Figure A-2. Regressions of Acquisition and RDT&E Cost Growth

The non-Gaussian distribution of the residuals limits certainty regarding the statistical implications of the regressions, but there seems little question that the trends are real and that the slopes are reasonably significant.

The eleven programs with inception dates between 1976 and 1979, inclusive, all fall below the trend both in development and total cost, the only substantial compact group of programs for which this is so.

Clearer insight is provided by the semidecadal[2] distributions presented above as Figure A-2. These give a strong impression that the five-year period between 1976 and 1980 was distinctly different from the period immediately preceding, and those which followed. The impression is confirmed by the results of pairwise, Kolmogorov-Smirnov, two-sided, two-tailed, statistical testing. The null hypothesis of identical distributions,

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[2] A statistical term from Latin *semi-*, half, plus *decadal*, of or belonging to a decade.

reported in Table A-1 and Table A-2, shows that the 1976-1980 period has strong measureable differences from the others.

Table A-1. Kolmogorov-Smirnov p values for Total Acquisition Cost Growth, by Semidecade

p	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000
1971-1975		0.0434	0.6430	0.9599	0.6481	0.2013
1976-1980			0.3251	0.4333	0.0231	0.0009
1981-1985				0.8318	0.4812	0.0069
1986-1990					0.3407	0.2689
1991-1995						0.0231
1996-2000						

Table A-2. Kolmogorov-Smirnov p values for RDT&E Cost Growth, by Semidecade

p	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000
1971-1975		0.0982	0.8408	0.6968	0.9739	0.8608
1976-1980			0.0637	0.4268	0.0902	0.1862
1981-1985				0.4651	0.5489	0.9489
1986-1990					0.7802	0.4896
1991-1995						0.6325
1996-2000						

All of the statistical calculations referred to were performed with a Microsoft Excel spreadsheet that is included among the files of Appendix D for full documentation.

Appendix B
Illustrations

Figures

Tables

Appendix C
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Appendix D
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Appendix E
Abbreviations

AAW	anti-air warfare
ACP	area coordinating paper
ACV	air cushion vehicle
AEC	Atomic Energy Commission
AEDC	Arnold Engineering Development Center
AEW	airborne early warning
ANVCE	Advanced Naval Vehicles Concepts Evaluation
ARPA	Advanced Research Project Agency
ASN(R&D)	Assistant Secretary of the Navy (Research and Development)
ASTF	Aeropropulsion System Test Facility
ASW	antisubmarine warfare
AV-MF	*Aviatsiya Voyenno-Morskoyo Flota* [Soviet naval aviation]
BSEC	Broad-area Surveillance Executive Committee
CAIG	Cost Analysis Improvement Group
CAPE	Cost and Program Evaluation
COMINT	communications intelligence
DCP	development concept paper *or* decision coordinating paper
DD(TWP)	Deputy Director for Tactical Warfare Programs
DDR&E	Director of Defense Research and Engineering *and/or* his office
DEPSECDEF	Deputy Secretary of Defense
DOD	Department of Defense
DSARC	Defense Systems Acquisition Review Council

DSP	Defense Support Program
FY	Fiscal Year
GATM	Global Air Traffic Management
GPS	Global Positioning System
HF	a radio frequency band, 3 MHz to 30 MHz
HP	Horsepower
ICBM	intercontinental ballistic missile
IR	infrared
ITSS	Integrated Tactical Surveillance System
JCS	Joint Chiefs of Staff
L/B	ratio of length/beam (of a ship)
MarAd	Maritime Administration
MDAP	Major Defense Acquisition Program
MDD	Matériel Development Decision
MHz	Megahertz
MIDAS	Missile Defense Alarm System
MIT	Massachusetts Institute of Technology
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NDRC	National Defense Research Council
nmi	nautical mile
NRL	Naval Research Laboratory
NSRDC	Naval Ship R&D Center
OSD	Office of the Secretary of Defense
OSRD	Office of Scientific Research and Development
OTHR	over-the-horizon radar

P.L.313	A professional and scientific service position established under Public Law 80-313
PA&E	Program Analysis and Evaluation
PPBS	Planning, Programming, and Budgeting System
Rad Lab	MIT Radiation Laboratory
R&D	research and development
RCS	radar cross section
RDB	Research and Development Board
RDT&E	Research, Development, Test, and Evaluation
ROTHR	Relocatable Over-the-Horizon Radar, AN/TPS-71
S&T	science and technology
SA	Systems Analysis
SAR	Selected Acquisition Report
SBR	space-based radar
SDDM	Secretary of Defense decision memo
SECDEF	Secretary of Defense
SECNAV	Secretary of the Navy
SES	surface effect ship
SOSUS	Sound Surveillance System
SURTASS	Surveillance Towed Array Sensor System
TAC	Tactical Air Command
TLR	top-level requirement
TPP	Total Package Procurement
TSS	Tactical Surveillance System
TTO	Tactical Technology Office
TWP	Tactical Warfare Programs
UAV	unmanned aerial vehicle

USAF	U.S. Air Force
USDRE	Under Secretary of Defense for Research and Engineering *and/or* his office
WARF	Wide-Area Research Facility
WSEG	Weapons Systems Evaluation Group
WSARA	Weapon System Acquisition Reform Act of 2009

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14. ABSTRACT

Defense acquisition programs, which had their initial inception in the 1970s, performed exceptionally well by many measures. The management of acquisitions during this period is examined in detail by means of case studies, and contrasted with earlier and later periods, to identify key factors and formulate promising policy initiatives. Previous findings about the crucial importance of decisions in the very earliest conceptual phase are strongly confirmed and success is shown to have very often hinged on effective intervention by the Director of Defense Research and Engineering (DDR&E) even before the equivalent of today's Matériel Development Decision. Factors in DDR&Es successes included a focus on the intersection of technology and military need, DDR&E's background of institutional success and the prestige and credibility it established, a compact and highly capable staff, a strong culture of objectivity and absence of either pessimistic or optimistic bias, excellent internal and external communications, a very sharp focus on things that made a real difference, and close meshing with the top management of the Department of Defense and its priorities. Finally, ways that these lessons could be effectively applied in today's environment are explored.

15. SUBJECT TERMS

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